that the public was being gradually educated to more stringent demands for fastness. Vat dyes very largely satisfied these demands but they could not be applied to all materials nor was it so easy to match shades with these dyes as it was with other classes of dyes only slightly inferior in fastness.

The lecturer described what were now known as vat dyes and the means of dyeing them based upon the use of the soluble leuco compound. These were reduction products and on oxidation the original insoluble coloured forms were secured on the fabrics under treatment. This to some extent explained the fastness of vat dyes. A brief historical outline of the dye-making industry was then given, and reference made to the work of Wohler, Perkin, Meldola, A. G. Green, Clavel, and others in this country and on the Continent.

The lecturer made special reference to the efforts to produce indigo synthetically and described the process now employed in its manufacture by the Society of Chemical Industry at Basle. The relative fastness of indigo on wool and cotton was discussed and its quality of fading pure emphasised.

Mr. Blair then proceeded to describe the progress made in the manufacture and use of anthraquinone vat dyestuffs—ranges made by various manufacturers being indicated. These dyes presented the highest fastness known among coal-tar dyestuffs. A brief résumé of the history of Sundour fabrics and their development followed, in which reference was made to the full story given by Mr. James Morton to the Royal Society of Arts in April 1929. Some reference was next made to the Hydron colours and to the relative cost of using vat dyes in place of other classes of dyes. Except in good depths of shade the extra cost per yard of fabrics dyed did not amount to much.

Finally, the lecturer came to the consideration of what should be understood by the public as fast dyes. The term was not the same to the purchaser of a casement cloth as to the purchaser of knitting wool. Tests for fastness to light, washing, water, alkali, acid, perspiration, rubbing, stoving, chlorine, and ironing were applicable and different dyes gave different results which should interest and inform the public. Three factors determined fastness—(1) shade; (2) purpose, and (3) kind of material. These points were elaborated by the lecturer, who described fastness tests employed by the Clayton Aniline Company, and the work of the Committee appointed by the Society of Dyers and Colourists to inquire into the possibility of defining degrees of fastness of dyed materials. A description of the Neolan colours, a speciality of the Society of Chemical Industry, Basle, was given and particulars of their use for wool, silk, and leather. The lecturer illustrated his discourse with tests, charts, and specimens.

A good discussion ensured in which many questions were asked from the point of view of the user as well as from that of the retailer or wholesaler. A hearty vote of thanks was accorded to the lecturer.

Scottish Section

Meeting at "Spread Eagle" Hotel, Jedburgh, on Wednesday, 22nd January 1930.

A party of about 22 members assembled at the hotel for lunch prior to visiting the works of Messrs. North British Artificial Silk Ltd., Jedburgh.

In the absence of Mr. Hartley, works manager, Mr. A. R. Knight extended a welcome to the Institute, and said that they were very pleased to have the opportunity of showing the members through the works that day. He hoped that the visit would prove of interest to all those present, and particularly those who handled rayon yarn in the course of their daily work. They would find no secrecy in the works, and were at liberty to ask any questions about particular processes viewed during their progress through the premises.

.., for their kindness and courtesy in allowing e members to visit the works, and said that they appreciated very much the irit which had prompted the directors to grant the necessary permission. eferring to Mr. Knight's remarks, he made an appeal for greater co-operation nong the members of the Institute on general subjects, and said that they need t be afraid of giving away any information on matters of common interest, ile there were many ways in which it was possible to work together for the nefit of the industry as a whole, and their own separate interests in particular.

Mr. J H. Lester, Manchester, a Vice-President of the Institute, who accompnied the party, also spoke, and appealed to members to realise that there were at possibilities for closer co-operation on the lines Mr. Brown had suggested, l that the activities of the Institute provided an excellent medium for co-'ination towards that end.

Thereafter the members spent a very interesting and instructive afternoon ting the works, conducted by Mr Knight, who gave a detailed explanation the various manufacturing processes employed in the production of rayon n

Irish Section

ting at Belfast Municipal College of Technology, Thursday, 23rd January 1930.

The second meeting of the session was held in the Municipal College of Tech-gy, Belfast, on Thursday, 23rd January 1930, when a lecture was delivered Ir W F Whiteford (London), on "Costs and Statistics for the Linen Trade."

Ir W. H Webb, who presided over a very large attendance, appealed for ger membership of the Irish Section of the Institute, and said every firm it to have at least one of its members subscribing Mr Webb said that in men trade they had got behind in administration, and that Germany and A. were far ahead of them in that respect, though not in technique He ght the report of the linen delegation to America was wonderful, and he d and believed it would mark a turning point in the trade

'r Whiteford delivered an interesting lecture, and spoke of the need for lard costs and up-to-date statistics for the trade

n the proposition of Mr. Garrett Campbell, seconded by Mr. F Anderson, rty vote of thanks was passed to Mr. Whiteford and Mr. Webb.

THE JOURNAL

of the

TEXTILE INSTITUTE

VOL. XXI—1930

PROCEEDINGS AND INDEX

THE JOURNAL OF THE TEXTILE INSTITUTE

XXI JANUARY 1930 No. 1

PROCEEDINGS

TEXTILE INSTITUTE ANNUAL COMPETITIONS

Distribution at the Institute, Saturday, 7th December 1929: Mr. E. C. Porter presided.

The Chairman, introducing Mr. T. Nuttall, Chairman of the British Cotton Industry Research Association, who was to present the prizes, expressed regret that illness had prevented Alderman H. Astley Bell from carrying out his promise to distribute the prizes on this occasion. He said he was sure that everyone in attendance would echo his thanks to Mr. Nuttall for accepting the engagement so readily and kindly at short notice. He called upon him with great pleasure to make the presentations.

Mr. Nuttall having distributed the prizes, said—Under ordinary circumstances I should not feel justified in coming here to distribute the prizes at this meeting because I know little about textile design and colour, my business activities having been confined to the production of grey yarns and cloth. However, I step into the breach because Alderman Astley-Bell has fallen ill at the last moment.

Now, in commerce, we are up against dislocation and difficulties, which have invariably followed war, but although ten years have passed, I cannot believe that the spirit of service and sacrifice, which defeated our enemies, will fail us now. A point which we are apt to overlook in these trying times is this, that had we lost the war our position would have been infinitely more uncomfortable. It is, of course, much more difficult to regain markets than to maintain them; it is not easy to create new markets and adapt ourselves to changed conditions. Therefore there is, more than ever before, a pressing need for mutual sympathy, co-operation, and a higher degree of technical training, artistic skill, craftsmanship, and research.

With regard to the latter, we are fortunate in the possession of an Institution unique in the history of the cotton trade. I refer to the British Cotton Industry Research Association. There we have a highly trained, scientific staff, with a fine equipment, working on problems of vital interest to the whole of the cotton trade. A vast store of vertical knowledge, extending from the cotton plant to the finished product, has been accumulated. To my mind it is impossible to set such a team to work without increasingly valuable results. There is now an opportunity for units, both large and small, to make use of information and help from this source, in addition to that of the Technical Colleges and Schools of Art. Workshops are in course of erection which will enable the staff to apply the results of fundamental research. A programme is being prepared for work on problems affecting the manufacturer; looms and sizing machines are to be installed with this end in view.

Some people say that they have no time to read the B.C.I.R.A. publications. This is, I think, their own loss, but even if no direct use be made of them, benefits must accrue beyond the value of the membership contribution, because of the widespread nature of the work. It matters little whether improvement comes from better growths of cotton, or improved spinning, provided that the spinner can make a cheaper and more level yarn containing fewer motes, specks, and neps, so as to enable the manufacturer to get more production and a slightly more perfect cloth of enhanced appearance by the use of a better dye or a more attractive design. It all means more demand for cotton, yarn, or cloth; increases its reputation with the customer, and leads to more business and prosperity for Lancashire.

Look for a moment at the sign of the times. In all ages there have been waves of unrest and desire for change and improvement. We are in the midst of such a movement now. Mr. Beck, The Solicitor-General of the United States, sees this exemplified in the current demoralisation visible in music, art, letters, and commerce. The essentially planless unrest in the field of art and letters is a reaction towards primitive chaos, and a mere imitation of the efforts of degenerate savages is not progress. The distorted shapes of "expressionist" sculpture resembles if anything the idols of West African negroes. "Futurist" painting with distorted shapes and a riot of shrieking colours is not real—unless bedlam be reality! The primitives knew nothing of perspective, but should we therefore deliberately discard the knowledge accumulated in later years?

The Haig Statue, says *Punch*, resembles Hindenburg, therefore let there be in Berlin a statue like Haig to the memory of Hindenberg. Horse, man, and equipment are all wrong, and the sculptor himself says that he did not intend the horse to be like a real horse! The works of Epstein are raising much controversy, but it seems difficult to justify their distorted shapes. One turns with thankfulness from these things to the Cambridge War Memorial. Quite simple, but figure, pose, and equipment are perfect. It is alive and beautiful; a boy soldier, moving with the ease and elasticity of youth. I saw Shaw's "Apple Cart" the other day. It is amusing and clever, so much so that one is apt to miss at the outset the degradation of the young man who ridicules and belittles the father who is dead. Nothing is sacred. Destructive criticism all through, leaving you bereft of faith and hope in God or man. "All Quiet on the Western Front," a book unnecessarily coarse and debased If you want horrors, read "Stories from Jutland" or "Into the Blue." These are quite as true as the former, but expressed with decency, and better calculated to cause us to pray and work for peace.

It seems to me that we ought to add to all the accumulated knowledge of the past, in order to produce better and more beautiful work, and thus turn to our advantage this desire for change. It may be necessary in some cases to produce for the moment as "pot-boilers," as it were, but I have sufficient faith in human nature to believe that even to-day good design and colour will command a better sale than bad.

Looking over the examples which were on view yesterday, I was astonished at the amount and quality of work accomplished in so short a time. Everyone who has obtained a prize undoubtedly deserves it, and is to be congratulated. It is evidence of effort and work, and in these days, when so many people ask "what is the Government going to do for me ?" it is distinctly refreshing.

Our fathers were brought up on Smiles' "Self Help"; believed in tact, push, and principle; and made the trade of Lancashire. Therefore there is a great opportunity to-day for the young man who elects to follow in his forefathers' steps, instead of waiting for someone to help him.

It was interesting to notice in the designs an absence of violent colour; in fact, indeterminate browns and mauves are prominent, and many of the designs are almost too quiet and lacking in boldness. Should not shirtings look fresh

and clean? A few gave the opposite impression, and appeared dingy. I once bought a suit of pyjamas which looked attractive, but had a raised figure. They were scratchy and most uncomfortable, and I was glad to see the last of them. Therefore the purpose for which the cloth is to be used should be kept in mind.

May I call your attention to the printed heraldic fabric on the wall? It is of high decorative value, and it possesses the characteristic brilliance of mediæval heraldry. Four colours only and two metals are used. The colours are red, blue, green, and black; the metals, silver and gold, otherwise white and cadmium yellow. The basic rule is never place colour on colour, or metal on metal. For instance, it is no use putting a blue lion on a black field, or a golden lion on a silver field. Could this be made use of in textile design?

I do not know if Ruskin is out of fashion, but even if he is, it might be well to read again what he has to say about colour and design. If he could have got rid of his prejudices against modern machinery, surely he would have delighted in the possibilities opened up by the use of rayon.

It is gratifying to find that the work has been sent in by so many Technical Schools. It proves that activity and endeavour are not confined to one place, and that teachers and students are making use of these local educational facilities.

May I be allowed to congratulate all those who have distinguished themselves by obtaining recognition to-day, and to give a word of encouragement to others, whose turn will, I hope, come later, and to add a word of appreciation of the work which is being done by the teachers to help us to bring renewed prosperity to Lancashire.

A vote of thanks to Mr. Nuttall was proposed by Mr. H. Bromiley, seconded by Mr. J. Read, and accorded heartily.

Institute Autumn Conference, London, 18th and 19th October 1929; Lt.-Col. B. Palin Dobson presiding.

THE TECHNICIAN AS A SALES FORCE*

By H. J. Clarke

I think it would be safe to assert that no phase of human activity has developed so amazingly during the last quarter of a century as Salesmanship. Every possible aspect of it has been subject to the most critical study; almost all branches of learning have been recruited to make its purpose more intelligently effective. It has been removed from the realms of mere exchange; the mechanical passing over of so much material in return for a suitable and requisite payment of money. It is something far more vital, and apart from the beneficial results of successful accomplishment, it is infinitely more interesting. It calls for an intimate knowledge of human nature and for a very full appreciation of all the conflicting emotions of life. As a study, the subject appears to have no limitations, and as long as human ingenuity can evolve new ideas, which in turn create new demands and consequent satisfaction, so will this great science develop.

Our interests to-day are in common; you are continually planning for increased output, and simultaneously we are organising for increased sales. Not an entirely selfish ambition, but one which in the achievement brings the joy of accomplishment in true proportion to the success of our efforts; and these efforts, if they are intelligently directed, must always be seeking for increased efficiency in every department of activity; not only efficiency of the cold-blooded type, the conditions of which merely register a safety-first freedom from error, but efficiency which bubbles with enthusiasm and is definitely infectious.

The craftsman with his skill, his untiring patience and ingenuity, and with his artistry and love of his job, was able to satisfy the few and somewhat simple

* **This is the full text of the paper delivered by Mr. H. J. Clarke at the Institute Autumn Conference, of which a report appeared in the November 1929 issue.—Editor.**

requirements of our forefathers. It would appear, however, that in many trades the craftsman of yesterday must, by sheer force of economic conditions, give way to the technician of to-day. But in supplying to the million what was limited to the few, let us not entirely lose the romance and glory attached to the production of beautiful merchandise.

The continual changing of conditions demand increased watchfulness, ingenuity, and adaptability. The greatest changes of all, as far as our particular interests are concerned, are, of course, dictated by that all-important factor, Fashion, and we have no quarrel with this supreme influence, which makes ever-changing demands for us to satisfy. The creators of fashion probably wield a greater influence in business than any group of corresponding size in the world, and are continually calling new branches of production to their aid. Compare the hosiery trade of to-day, with its range of materials and bewildering array of shades and colours, to that of a few short years ago, with its limited assortment of cashmeres and cottons. The shoe manufacturer is no longer restricted to the use of a few strong and sturdy skins, which produced an article mainly utilitarian, but, to satisfy the popular demand for novelty, must seek out every beast and reptile that crawls on the earth and many creatures that swim in the sea. All are brought to pay tribute to Dame Fashion—and to increase business! Enter the piece goods department of any big retail establishment, examine the amazing assortment of materials displayed, and compare this to the limited range of ten or fifteen years ago.

These changes and developments have created new problems and greater responsibilities for the retailer. The ever-increasing complexity of merchandise, with new markets continually coming into being, demands the closest possible acquaintance with detail. They have also called for a higher standard of what I will term service salesmanship. This must not be looked upon as a refinement, a slogan which sounds a good advertising argument, but something that the customer can justly expect, something which is actually a part of the cost in marketing the goods. "Sales without service," in its fullest meaning, cannot be productive of that precious possession—good-will. This brings me to a "close-up" of the text of the talk—the ever-increasing necessity for a greater knowledge of merchandise by those engaged in the task of selling it—not the type of information picked up at random and used in parrot-like fashion to push a sale—but definite and intelligent acquaintance with facts which will materially assist both salesman and purchaser alike. Knowledge is strength, and the organisation that possesses a staff well equipped is in an impregnable position. A lost sale rather than the disposal of material unfitted for the required purpose should call for commendation rather than rebuke. I have an increasing distrust for the fellow who claims that he can sell anything; perhaps he can, but it is more than likely that he will prove mighty dangerous to any organisation. Sales for the mere sake of selling, quite apart from filling clearly defined requirements, may add to *volume*, but they are of doubtful ultimate value.

So here is our problem and our responsibility; if we recognise the wisdom, the sheer necessity of the service and our absolute obligation to give it, then every available opportunity of training must be utilised. Like every other form of education, it must first deal with elementary facts. The story of the silk-worm must certainly precede blue prints of the latest machinery used in manufacturing the fashionable material of the day. The curriculum must be planned, step by step, in natural progression if the interest of the student is to be maintained; and I would like to urge that at every stage stress should be laid on the *why* as well as the *how* of manufacturing practice; the significance of this point will be obvious to all engaged in sales promotion.

These comments may be interpreted as an inference that this all-important work has not begun. It may be taken to infer that my remarks are put forward as a new idea concerned with the science of salesmanship. That, of course, is

not the case; I definitely desire to emphasise the importance of the technician in the general scheme of affairs, and to indicate the desire for a still closer co-operation. Excellent work is already being done, and the splendid assistance of the experts is tremendously appreciated. It is our great wish to become better acquainted. Mr. Technician, come sometimes from your looms and laboratories, from your stink cupboards and synthetics, and meet the people who put the finishing touches to your job—those who sell your production to the consumer. Come and get a little first-hand knowledge of the man at the other end; witness the association between salesman and customer, with your cherished productions as the point of contact. You will then better appreciate the type of information which will help to build a still greater confidence between salesman and customer.

The technician has already become a definite factor in the operations of many big retail organisations. The merchandise division of the business with which I am associated has for many years had the service of a full-time research chemist. His expert knowledge is of immense value to our buyers, and the selection of materials is constantly based on the analysis and test results submitted by this authority. Strength, colour fastness, tendency or otherwise to shrinkage, are all points of utmost importance, and surprising facts are sometimes demonstrated as a result of exhaustive examination. In the laboratory, customers' complaints regarding merchandise are scientifically investigated, not in the spirit of self-defence, but to get intelligent information which can be utilised to good purpose. Meantime, the customer has assuredly been satisfied without waiting for any report from the manufacturer. Whether satisfaction comes from this quarter or not, the responsibility is definitely ours and we accept it gladly. The expert controlling this important task is directly linked up with staff educational work, and, apart from the technical side, has a keen appreciation of the selling value of the information he is able to impart. At the present moment about one hundred and fifty of the staff are attending lectures given by him, dealing with appropriate technical aspects of the goods with which they are closely associated. From the laboratory emanate technical bulletins, published at regular intervals, containing results of tests and investigations, which are of enormous value to many departments. Here then is a very definite and practical appreciation of the technician as a sales force.

Mention has already been made of acceptance of responsibility for all goods sold to the retail customer, and I venture to suggest that the subject of the paper permits a further reference to the matter, this time in association with the manufacturer. Of the complaints received, many are absolutely justified, the bulk reasonably so, and comparatively few can be classed as frivolous and unjustified. These latter can be dealt with according to circumstances, but the others certainly do not create confidence if subject to lengthy argument and consideration. If a concession or even an admission is to be made, quickness of decision and graciousness of announcement win the greatest possible value out of the occasion. Here is a fine opportunity to strengthen the hand of the salesman, so do not let it be wasted! The defensive attitude creates irritation and an atmosphere antagonistic to good relationships. I am tempted to mention an instance recently referred to in a report from our own laboratory. Certain woollen articles having been returned to us with a complaint of shrinkage, a sample from the same stock was washed in precisely the same manner as that described by the complaining customer, and the result was uniform with her experience. Lengthy correspondence with the manufacturer followed, and despite the obvious failure of the goods, a stubborn defence was maintained. It is not known whether this attitude was an indication of policy or the self-defence of a technician—that was not our concern; the immediate task was to find another source of supply where there would not be risk of any further experience of this kind.

If I am, in passing, to make any remarks on textile manufacture, they can only be associated with criticisms intended to be constructive and helpful. The

great bulk of our textile merchandise is of satisfactory character, but as I have already said, our research laboratory has deliberately spent much time on the investigation of complaints in order to gain information on the causes of failure in actual use.

In manufacture a long-sighted view is necessary. When considering the design and properties of his fabrics, the manufacturer should not only consider how they will appeal to the wholesale or retail buyer or how they will attract the customer, but he should also determine what service they will give in normal usage by the consumer. This point may seem very obvious and elementary, but our experience shows it is sometimes overlooked. You have a large number of beautiful dyestuffs of various types. Some are fast to sunlight, or to washing, or to perspiration, or other factors, and some are fast to all these; but some are very fugitive in one way or another. In samples of wool dress fabrics, we find about 5% with colour so fugitive to light that they are unfit for outdoor wear. In furnishing fabrics offered to us as "fadeless," we find about 4% are unfit for furnishing fabrics on account of low colour fastness to light, and another 14% are only of ordinary quality fastness, and so are unwarrantably described as "fadeless." We have had wool hose coloured with acid dyestuffs—a type of dyestuff which is generally loose to washing, and, moreover, with the dye loosened from its combination by washing; so they have not only lost colour in washing, but thereafter they have stained or dyed the feet. Do not give us beauty of colour alone, for we require reasonable fastness as well; do not say that price considerations prevent the application of fast colours, for I am informed that the extra cost of using satisfactory dyes is small.

Again, in the finishing of fabrics you have machines which can stretch the material in width or length or both. This process has its legitimate use, but it leads to very serious trouble if it is abused. Fabrics so stretched retain their size while they are dry, but once they get wet (as in washing) they revert to their normal size. Our main source of complaints is with defective colour fastness, but the next most serious source is concerned with the shrinkage of stretched fabrics. The third in order of number of complaints is concerned with the perishing of weighted silk, either by the action of sunlight or by the action of sunlight and perspiration.

The wrong attitude to take is illustrated by the following experience. Among a number of samples of rayon frock material we were testing was one fabric which had unusual and objectionable shrinkage, and, moreover, the colour faded seriously after two days' exposure to summer sunshine. We wrote to the dyer and finisher of this material (which was intended for washing-frocks and for outdoor wear, and would fail lamentably in both respects), asking for his comments. These were that the material was finished to the width and length the manufacturer specified, and that dyeing presented problems, and that it was essential to get a "merchantable article." This was a "merchantable article" in the sense that the merchant would think it all right, but assuredly it was a wrong and foolish policy to produce such a satisfaction-destroying fabric. I am, of course, well aware that in many cases special novelty or elegance in fabrics can only be obtained at some loss to what I will call the utility of the cloth, but in leaving this subject I suggest that the amount and consequence of such sacrifice should always be carefully weighed.

It might be advantageous to consider the technician as an instrument of publicity in the field of salesmanship. I am inclined to think that he has a very definite place in its operations. I am not about to suggest that we would give serious consideration to filling our expensive advertising columns with a series of scientific articles on the development of the automatic loom, neither do I think it likely that a treatise on the relative values of vegetable and aniline dyes would result in an immediate rush of customers. But the copy writer would rejoice in the acquisition of information relating to the romantic side of research

discovery and ultimate production. When television is a complete and accomplished fact, I venture to think that the story of the early struggles of its inventor, his sudden inspirations, his numberless failures constantly in fluctuation, will not be the least interesting part of the history. There may be many of my readers who have learned the bitterness of disappointment before experiencing the joy of ultimate success. Again, what a fascinating story could be written of the great discoveries that have been revealed almost by accident, looking for one result and finding another infinitely greater than the original objective. Such experiences are not confined in interest to such events as the origination of glass or the discovery by the Phœnicians of Cornish tin. They have occurred right down through the industrial age, but I am inclined to think that the majority of us have but a limited knowledge of them. Advertising, that most important adjunct to salesmanship, so closely allied that it is almost a part of it, has to seek continually for new methods of attraction and conviction, and I suggest that the most lasting and effective means of creating interest is to tell some story about the article advertised. The most obvious means of this information reaching us is through the medium of the man selling us the goods, but what about his knowledge on the subject? Is he kept acquainted with the points of manufacturing interest to which I refer? A much closer association between the technician and the traveller on the selling side might be advantageous to all concerned. Certainly a closer co-operation would have a vast influence on foreign trade

I will conclude with a very sincere appreciation of the work of the Textile Institute. The only thing I can find to complain about is its modesty; I mean this, and suggest in all seriousness that this, and much other good work of a similar nature, does not receive the publicity it deserves. Moreover, its usefulness is definitely restricted on this account. I think that the same could be said of that wonderful organisation, the Manchester College of Technology. Has the man in the street ever heard of it? Has its amazing sphere of usefulness ever been referred to in any but scientific or technical circles? Is this due to our English modesty or is publicity considered an undesirable companion for science? Skilful propaganda and well-directed publicity will not only add to our national pride for work well done, but will result in added efficiency in every branch, and serve as a still greater incentive in the search for knowledge by the young people in our trade.

Lancashire Section

THE PHYSICAL AND CHEMICAL PROPERTIES OF CELLULOSE IN RELATION TO TECHNICAL TREATMENT OF ARTIFICIAL SILK

At a meeting under the auspices of the Lancashire Section of the Textile Institute, held at the Art School, Macclesfield, on the evening of Wednesday, 27th November 1929, Mr. A. W. Hewetson, Vice-Chairman of the Higher Education Committee, presided, when a lecture on the above-named subject was given by Mr. A. J. Hall, B.Sc., F.I.C., F.T.I. The following is a summary of Mr. Hall's contribution, which proved of exceptional interest—

Ultimately the essential properties of artificial silk yarns and fabrics are dependent on the characteristics of the individual fibres and, because of this, research dealing with the physical and chemical properties of such fibres is of the utmost importance. It is believed that individual artificial silk fibres consist of innumerable micelles characterised by having a much greater length than diameter, and that these micelles may be arranged in chains along the length of the fibre or in various directions. It is also believed that when the micelles are in

chain form they are held together by attractive forces between their ends and that the structure of the fibre is then much more permanent and resistant to physical and chemical forces than when the micelles are arranged indiscriminately. The properties of artificial silk materials shown during dyeing and finishing processes can be co-related to this micelle structure. The orientation of the micelles in artificial silk fibres is largely governed by their treatment during manufacture. Any stretching process to which the fibres are subject whilst in a plastic state is favourable to the orientation of the micelles in chain form. This fact is of importance during the spinning and coagulation of the artificial silk fibres and during their drying, since at both these stages stretching may have a marked effect. Thus it is found that cellulose artificial silk fibres produced by the stretch process (for reduction of denier) have less extensibility than those produced with a minimum of stretching and is the expected result of an increase in the chain structure.

It is found that artificial silk yarns have increased lustre as the degree of parallelism of the fibres is increased. Similarly an increased parallelism of the micelles in individual fibres (equivalent to increased chain structure) should result in greater lustre. This is a common observation—that brightness in artificial silk materials is produced by stretching.

The affinity of artificial silk fibres for dyes is dependent on the degree of dispersion of the cellulose of which they consist; the greater the dispersion the greater the affinity. It can be assumed that the dispersion is least when the micelles are in chain formation. The direct inference is that stretching would decrease the affinity of an artificial silk for dyestuffs, and technical experience shows this to be the case. In the dyeing of artificial silk materials it is important to pay attention to the conditions of dyeing, particularly the degree of stretching to which the material will be subject whilst absorbing dye. Obviously the material should be subject to a uniform tension if it is subjected to tension at all.

In finishing operations, particularly those dealing with fabric, it nearly always happens that artificial silk materials are stretched. For instance most fabric is passed over a stenter to stretch it to the desired width. Investigations shortly to be published by the lecturer have shown that such stretching considerably decreases the softness and resistance to creasing of all artificial silk materials. Designers of fabrics should therefore be most particular in arranging that the finisher has to use the least possible stretching to bring it to width. Experience shows that designers have not fully appreciated this point.

All technical processes for the treatment of artificial silk materials have a small or large effect on the orientation of the micelles in the individual fibres with consequent effects which appear during the progress of the treatment or as permanent effects in the treated material. This applies to such processes as dyeing, boiling with scouring liquors, subjection to alkalis as in mercerisation processes, drying with and without tension, and finishing. In most cases the effects can be co-related with the disposition of the micelles, but this field of research requires much extended cultivation.

The Chairman said they were greatly indebted to Mr. Hall and to the Textile Institute for having provided so informative a lecture. The previous year, a similar meeting was held when the weaving of artificial silk was expertly dealt with. It was fitting, therefore, that another aspect of a big subject should now be under consideration. Artificial silk was of great importance to Macclesfield and had benefited local industry considerably.

On the motion of Mr. G. H. Stafford (Hyde), seconded by Mr. C. M. Whittaker (Cheadle Hulme), a hearty vote of thanks was accorded the Lecturer and Chair-

Scottish Section

Meeting in Cranston's Picture House, Glasgow, on Wednesday, 18th December, at 10.30 a.m.

The attendance numbered 140, comprising members and friends, also representatives of the various textile interests in the West of Scotland.

The Hon. Secretary, Mr. A. W. Blair, explained that the meeting had been arranged in Glasgow principally for the benefit of members in the West of Scotland. The Scottish Section being a very widely scattered body, it was not always possible to arrange meetings in one centre convenient for every member, so the Section Committee had followed the policy of arranging meetings in different parts of the country, the last being in Perth at the end of October, and the next to be in Galashiels at the beginning of February. He also intimated that the Directors of North British Artificial Silk, Ltd., had given permission for a party of members to visit the works at Jedburgh, and this would likely take place early in January. Mr. Blair explained briefly the objects of the Institute, and said that while a meeting of that kind was only a small part of the Institute's activities, it might serve to demonstrate to non-members part of the work which was being carried on in an effort to spread a knowledge of textile science, and to encourage the free interchange of views between members. He hoped that the meeting would be of sufficient interest to attract some of those present who were not yet members of the Institute, and intimated that copies of the prospectus and annual report would be available for distribution at the end of the meeting.

Thereafter two films of particular interest to the textile trade were shown, viz., "The Vickers Stafford Automatic Loom" (by courtesy of Messrs. Vickers (Crayford) Ltd.) and "The Romance of Rayon" (by courtesy of Messrs. Courtaulds Ltd.). The films were followed with keen interest by those present, and at the close Mr. J. P. Beveridge, Dunfermline, expressed a word of thanks on behalf of the Scottish Section to Messrs. Vickers and Messrs. Courtaulds for their courtesy and assistance in enabling these films to be shown.

Irish Section

Meeting at the Municipal College of Technology, Belfast, on Thursday, 5th December 1929; Mr. H. C. McCleery in the chair.

PEDIGREE FLAX SEEDS

Mr. G. O. Searle delivered an interesting lecture on the above subject, during which he described work which had been going on during the past ten years at the Linen Industry Research Institute. The following is an abstract of his lecture.

It might be thought in this time of trade depression only a super-optimist would contend that money expended on flax breeding work was worth while, considering the very long time which usually elapses before tangible results are reached. It is fortunate therefore that the far-sighted originators of the Linen Industry Research Association saw to it that the foundations of such work were well and truly laid some ten years back when conditions were not so difficult as they are now. In consequence the somewhat nebulous hopes of those days have very nearly become solid realities.

In view of the stress that has been laid on the value of standardisation in the linen trade, it is not out of place to point out that flax breeding is pre-eminently a shining example of the application of standardisation. A field of ordinary flax is a complex assemblage of good, bad, and indifferent units, and the plant breeder's business is to isolate and assiduously cultivate those lines which, in the words of the Linen Trade Delegation, will meet consumer acceptance.

Some members of the trade take the line that flax breeding is a very interesting pursuit, but not really their concern. It is, however, very much their direct concern, as everything points to the probability that the widespread introduction of pedigree flaxes to the growers will be a decisive factor in meeting that most

urgent demand of the trade, an ample supply of raw material at the right price. With prices as they are to-day, Irish flax at £70–£75 per ton, and with the ordinary kinds of flax giving only an average of 30 stones per acre, flax growing becomes a hopeless proposition, and it cannot be wondered that the acreage continues to dwindle. It is impossible to introduce mechanisation or mass production methods to a peasant farmer working a few acres of land; his costs of production are already at bed rock. Save for raising the price of flax there would appear to be no alternative solution to that of supplying the farmer with better varieties of seed, so that without much added outlay on his part he can wrest a somewhat bigger return from his land.

Although the provision of pedigree seed for Northern Ireland must be taken as a primary object, a much wider application of this work is foreseen, namely, the development of a flax industry in other parts of the Empire. Experiments have shown that in certain of the Dominions and Colonies a profitable fibre and seed industry could be organised, whilst other parts unlikely to be suitable for fibre production would be eminently satisfactory as seed bulking centres to supply large quantities to Northern Ireland, where, chiefly for climatic reasons, normally no seed is saved from the crop. There is no valid reason why the present unsatisfactory and fluctuating supplies from the U.S.S.R. and Baltic Provinces should not be wholly supplanted by a steady and ample supply of flax from within the Empire.

The actual breeding of pedigree flaxes is somewhat laborious. The important part of the plant, namely, the fibre, is an internal characteristic, and as all plant breeding is based on a study of a number of plants taken singly it was necessary to devise a way of determining the fibre content of single plants. This has involved the microscopical examination of thin sections of the flax stem and the measurement of the fibre content of many thousands of plants. The percentage of fibre in a flax straw is a strongly inherited characteristic, but it varies over a wide range from straw to straw in a field of ordinary flax quite irrespective of the external appearance of the plants. The general plan therefore has been to select and breed from those plants which had the maximum percentage fibre content, as shown in the transverse section.

Notwithstanding the antiquity of flax cultivation, very little breeding or selection of seed had been done up to a few years ago. The first big advance was the production and introduction to the market of the J.W.S. flax, which because of its greatly increased length of straw gave an increased yield of 50% of fibre per acre. Later work has been mainly concentrated on producing flaxes which notwithstanding their being shorter would give a yield of fibre even greater than the J.W.S. At the present time the Linen Industry Research Association is propagating some thirteen or more new varieties, under the name of Liral flaxes, which in their diverse characteristics should satisfy every requirement of the grower both as to yield per acre and quality of fibre. The J.W.S. flax was first selected about the year 1911, and in 1929 there was approximately 12,000 acres of it growing in England, Northern Ireland, and Canada. The new Liral flaxes are in all stages from about 20 tons of seed downwards.

The chief problem in this work lies in the bulking of the flax seed to commercial quantities. In order to bring the matter to a successful issue up to 2,000 tons of pedigree seed is desirable each year for Northern Ireland alone, and to produce this needs some 12,500 acres of flax grown elsewhere. At present there is less than 3,000 acres per annum being grown in England, but with suitable organisation this acreage could be profitably increased to a great extent. Normally flax grown for fibre gives only a four-fold return of seed, but sowing thinly enables this yield to be increased to fifteen-fold or thereabouts, but then the straw is of little use for fibre, so this method has a limited application.

Generally speaking, we would appear to be ahead of all other countries in flax breeding. Strains have been evolved in Denmark, Holland, Germany, and America, but in each case keeping the strain pure and bulking it to commercial scale has not been so successfully done as it has at home.

It is imperative to realise fully that pedigree flax production must go hand in hand with research into the processing of the fibre. The present methods of harvesting, retting, breaking, and scutching can and should be very greatly improved so as to obviate the enormous loss of fibre or degradation into tow which at present occurs.

What the extent of the potential improvement might be is difficult to estimate exactly, but given an ample supply of pedigree seed and such improvements in methods as are already in sight, there should be no insuperable difficulty in increasing the return in Northern Ireland from the present average of 30 stones of fibre per acre on 30,000 or so acres to 50 stones per acre on 50,000 acres.

The main point is that notwithstanding the existing depression, flax as an agricultural product has enormous potentialities, and if only we can devise better ways of processing the better kinds of flax now becoming available, flax growing as an industry could become Empire wide, and linen would regain its ancient and honourable position as the paramount textile of the world.

On the proposition of Mr. J Gray, seconded by Mr. W. H. Webb, a hearty vote of thanks was passed to Mr. Searle and to Mr. McCleery.

NOTES AND NOTICES

Institute Membership

At the December meeting of the Council of the Institute, the following were elected to membership—G. R. A. Ainsworth, Waverley, Central Avenue, Levenshulme, Manchester (Representative of Asa Lees & Co. Ltd.); H. L. Baron, B.Sc. Tech., The Cedars, Great Harwood, Blackburn (Salesman); R. R. Colmar, 66 Siward Road, Bromley, Kent (Textile Tester), John Hunt, 457 Prettywood, near Bury (Loom Overlooker); N. Illingworth, 25 Stephenson Street, Great Horton, Bradford (Assistant Manager, Textile Factory); Lloyd Knibb, 37 Bond Street, Higher Broughton, Salford (Yarn and Cloth Tester); W. P. Knowles, 12 Derby Road, Spondon, Derby (Weaving, Technical Service), Vincent Lee, The Laurels, Summerseat, near Bury (Cotton Piece Goods Salesman); Wm. Marsh, 243 Chorley Road, Swinton, Manchester (Jacquard Harness Gartor); A. Matley, 30 Sunny Bank Road, Lees, Oldham (Cotton Spinning Piecer); Stanley M. Mather, Mahony Road, Wentworthville, N.S.W., S. Australia (Cotton Mill Carder); J. M. Shah, 107 Great Stone Road, Chorlton-cum-Hardy, Manchester (Textile Student); M Tomlinson, M.A , Principal, Municipal Technical College, Broad Street, Bury (Director of Education, Bury), R. L. Wood, 2 Mayfield Road, Bentham, nr. Lancaster (Weaving Shed Manager); W. A. Dickie, Weaving Dept., British Celanese Ltd., Spondon, Derby, has been elected to Life Membership.

At the January meeting of the Council of the Institute, the following were elected to membership—C. H. Edwards, 28 Norton Street, Radford, Nottingham (Asst. Departmental Manager), R. K. Eskew, Du Pont Viscoloid Co., Chem. Dept , Arlington, N.J., U.S.A. (Research Chemical Engineer); A. H. Grimshaw, North Carolina State College, Raleigh, N.C., U.S.A. (Teacher, Textile Chemistry); W. H. Johnstone, c/o Preston Steam Laundry Ltd., Addison Road, Preston (Manager); V E. Naidu, c/o Sholapur Spinning and Weaving Co. Ltd., Sholapur, India (Asst. to Carding and Spinning Master); J. Guthrie Oliver, 4 York Street, Manchester (Journalist); W. Sharratt, M.Sc., c/o Harbens (V.S.M.) Ltd., Golborne, nr. Warrington (Chemist); E. Smalley, Kingsland, Rochdale (Salesman of Textile Machinery); A. R. Thomson, American Consulate, Ship Canal House, King Street, Manchester (Consul of U.S.A.); Thos. Wright, 4 St. John's Street, Pendlebury (Cotton Spinning Teacher).

Annual Election of Council

The By-laws of the Institute provide that "at least . . . ten ordinary members of Council shall retire annually . . . but shall be eligible for re-election." etc. Furthermore, a list of such vacancies has duly to be prepared

by the Council and published in the *Journal*. At its meeting on Wednesday, 15th January, this duty was carried out, and below is given a list of members of Council in the order in which, save for extraordinary reasons, they are due to retire. By instruction of Council a list of attendances, not only at Council meetings but at Committee meetings also, is supplied. Nomination forms in connection with this election are being prepared, and will shortly be issued to all members.

Attendances at Council and Committee Meetings

From April to December, 1929

	Council 8 Meetings	Finance Committee 8 Meetings	Selection Committee 7 Meetings	Publications Committee 8 Meetings	Competitions Committee 2 Meetings	Propaganda Committee 5 Meetings	Lancashire Section Committee 1 Meeting	Yorkshire Section Committee 3 Meetings	London Section Committee 5 Meetings	Library Committee 4 Meetings	Research, Testing, and Inventions Advisory Committee 3 Meetings
To RETIRE 1930—											
Barwick, F. W. ...	2	—	6	0	—	—	—	—	—	—	0
Beveridge, J. P. ...	1	—	—	—	—	—	—	—	—	0	—
Boothman, W. T. ...	3	—	—	—	—	0	0	—	—	—	—
Kershaw, W	7	6	—	7	1	—	—	—	—	—	—
Morley, T	0	—	—	—	—	—	—	—	—	—	—
Morton, W. E ...	0	—	4	2	—	0	—	—	—	—	—
Nasmith, F	5	5	—	—	—	3	1	—	—	—	0
Robinson, J.	0	—	—	—	—	—	—	2	—	—	—
Watson, S.	1	—	2	—	0	—	0	—	—	—	—
Withers, J. C.	5	—	2	8	—	—	—	—	—	0	—
To RETIRE 1931—											
Bailey, R. G.	1	—	—	—	—	0	—	2	—	—	—
Bailey, W	3	—	3	—	—	0	0	—	—	—	0
Chance, F S.	†	—*	—	—	—	—	—	—	—	—	—
Davis, W	2	—	1	—	—	—	—	—	—	—	1
Hall, A J.	2	—	—	4	—	—	0	—	—	—	1
Lishman, W W. L ...	1*	—	—	4	—	—	1	—	—	—	—
Midgley, E.	3	—	2	—	—	—	—	3	—	—	0
Nisbet, H.	8	—	—	8	—	—	1	—	—	—	—
Shearer, A. B	1	—	—	—	0	1	—	—	1	—	0
Wilkinson, W.	0	—	2	—	—	—	1	—	—	0	1
To RETIRE 1932 ...											
Binns, H.	6	4	6	—	—	—	—	3	—	—	—
Cockroft, E. E. ...	0	—	—	—	1	—	—	—	—	—	—
Fletcher, J. F. ...	3	—	—	1	—	—	—	—	—	—	—
Ickringill, C. S. ...	4	—	—	4	—	—	—	3	—	3	—
Read, J.	4	—	—	5	—	—	0	—	—	4	0
Richardson, H. ..	4	3	—	6	—	—	—	0	—	—	—
Robinson, T. F ...	7	7	—	—	—	4	1	—	—	—	—
Slater, F. P.	4	—	—	3	—	—	—	—	—	—	—
Speakman, J. B. ...	1	—	—	1	—	—	—	—	—	—	—
Wigglesworth, E. ...	1	—	0	—	—	3	—	—	2	—	—

— Indicates not a member of the Committee.
* Only one attendance possible.
† Elected January 1930.

Examination in General Textile Technology

At the recent examination of applicants for the Associateship of the Institute, held at Headquarters, on the 4th December 1929, there were twelve candidates, the largest number recorded since the examination scheme was introduced. At the January meeting of Council, the recommendations of the Selection Committee were approved whereby the following candidates are certified as having passed the examination—C. Barrow (Manchester), J. Aspden (Clitheroe), G. D. Sutton (Bolton), B. Etherington (Rochdale), W. L. Stuart (Halifax), J. Pilkington

(Oldham), J. R. Whitworth (Oldham). The passing of the examination completes the qualifications required on the part of the members' names for the Associateship of the Institute. The next examination will take place in June, and the date of the event will be announced later. Unsuccessful candidates at the last or a previous examination may apply for permission to present themselves again. In regard to new candidates, however, the fact may now be usefully restated that the examination is only available to members of the Institute who have made application for the Associateship and whose record of attainments have been adjudged by the Selection Committee as otherwise satisfying the requirements of the printed regulations.

REVIEWS

Blanchiment. By A. Chaplet. Published by Gauthier-Villar & Cie, Imprimeurs-Editeurs, 55 Quai des Grands-Augustins, Paris (362 pages and index).

This is the second edition of a comparatively well-known book on bleaching, and in its production considerable amplification and remodelling have taken place. It treats in a general way with bleaching, not only of materials used in the textile industries, and in every commercially available form, but also of the application of the bleaching process to the whitening of foodstuffs, such as flour, etc. It is therefore unique in its comprehensiveness, though it is obviously impossible to produce a very detailed technical account of the various branches of the bleaching industry in such a small volume. The first portion of the book is devoted to the various machines and appliances used in the bleaching and allied treatments of textile materials. This chapter is profusely illustrated with diagrams and photographic reproductions of machines, the majority of which are of Continental origin. The machines dealt with relate principally to impregnation processes, scouring and boiling processes, washing, drying, etc. The second part of the book, which is devoted to scouring and boiling, as employed in the purification of textile materials, treats in a brief way of the various chemical reagents used therein, and of the action of the better-known detergents. Chapter IV gives a detailed account of the oxidising and reducing substances used in the washing of textile fibres, yarns, and fabrics. A series of articles then appear on the actual bleaching of vegetable and animal fibres, including straws and wood. The latter portion of the book is devoted to the bleaching of foodstuffs, fatty matters, etc., and includes flours, starches, sugars, oils, fats, and waxes of vegetable, animal, and mineral origin, fruits and vegetables, soaps, gums, resins, and certain mineral substances. A short chapter is also included on the faults arising in bleaching, the testing of materials used in the bleaching industry, and the installation and arrangement of works. A bibliography is also included. The book, though of somewhat superficial character, is well written and arranged, and contains a fund of useful information in a convenient form.

W.K.

Ein Beitrag zur Seidenbaufrage. By Dr. W. R. de Greiff Published by Julius Springer, Berlin, 1929. (Rm. 7.)

This unusual miscellany of 100 pages describes the rearing of the silkworm, the production of raw silk, and the distribution of silk culture throughout the world. The numerous well-reproduced photographs show many of the operations in progress and the surroundings in which they are carried out. The contents include also a few pages on artificial silk and methods of distinguishing it from natural silk; and an account of the author's investigations on the winding of Chinese, Japanese, and Italian silk from the cocoon and on the tensile properties of silks of these various origins. A short discussion of the history of silk culture in Germany leads the author to the conclusion that the conditions there are not favourable to its successful development. W.D.

Seidenbau und Seidenindustrie in Italien. By Dr. Hans Tambor. Published by Julius Springer, Berlin, 1929. (Rm. 10.)

This economic study (apparently in its origin an academic thesis) of the cultivation of silk and of the silk industry in Italy from the foundation of the kingdom down to 1925 is a thorough piece of work; but it would make easier reading if the

numerous statistics had been more frequently displayed in tabular form rather than sunk in the text. Nevertheless the story told here of the recovery of the Italian silk industry from the effects of disease, of the influence on it of agrarian conditions, tariffs, Asiatic competition, and so forth, and of the development of silk manufacture in Italy, is one of great interest, particularly to the economist; technical questions are not discussed unless in so far as that is necessary for the development of the economic theme. W.D.

Technologie und Wirtschaft der Seide. By Dr. Herman Ley and Dr. Erich Raemisch. Published by Julius Springer, Berlin, 1929. (Rm. 66.)

This is the second part of Volume VI of the handbook on the "Technologie der Textilfaser" now being issued under the general editorship of Professor R. O. Herzog; the first part, which will be concerned with the silkworm from the entomological and biological standpoint, is still in the course of preparation. The present work is composed of a technological part by Dr. Ley which occupies 485 pages, and of a very competent and informative survey of the world's silk industry and trade by Dr. Raemisch, which occupies the remainder of the 530 or so pages of text.

The technological part is composed of four main sections. which deal respectively with the preparation of raw and thrown silk; that of spun silk; the degumming, bleaching, weighting, dyeing, and finishing of silk yarns; and the same processes with printing in addition as applied to woven fabrics. The last section includes also some description of various silk fabrics and illustrations of them; but mechanical details of weaving and knitting are intentionally omitted, and for these reference is made to the earlier volumes of the handbook which deal with these topics. Thus two sections, or about three-quarters of the technological part, are concerned mainly with degumming, weighting, dyeing, finishing, and similar processes which are fully described. with illustrations of the plant employed, and citation of the relevant patents. Perhaps these sections may be regarded as an amplification of the author's well-known and useful work "Die Neuzeitliche Seidenfärberei."

The two earlier sections deal respectively with the preparation of raw and spun silk yarns The characteristics of the cocoon in relation to race, origin, and quality, the various processes by which grège (raw silk in the narrower sense), and thrown silk are prepared, and the methods of testing both grège and thrown silk are very well described with the aid of numerous illustrations, among which may be mentioned that of Serrel's automatic device for reeling from the cocoons and that of a cross-section of a cocoon thread showing the secondary fibres recognised by Wagner.

In the relatively short section on the spinning of silk waste the survey of methods for the degumming of waste is of some interest; besides boiling the waste with soap as is usual in this country or with soap and sodium carbonate with a forced circulation of the liquor as appears to be more usual abroad, foam degumming, and the treatment of the waste with soap, alkalis, or solvents for fat in closed, rotating drums are said to have established themselves. The processes of dressing (chiefly with reference to rotary frames) and spinning are sufficiently described, but not in any great detail.

This book is a welcome addition to the somewhat scanty literature of the silk industry. W.D.

Technologie der Textilfasern. VIII. Wollkunde. By Fröhch, Spöttel, and Tänzer. Published by Julius Springer, Berlin. (Price Rm. 54.)

It is only comparatively recently that in England the scientific study of wool—both as a natural material possessed of remarkable physical and chemical properties, and as a textile fibre—has been recognised as an occupation worthy of pursuit. Hence it is not surprising that there is a lack of any comprehensive treatise in our language dealing with wool and wool growth.

The volume under review, which is the last of a series of eight dealing with the more widely used textile fibres, goes some way towards filling such a place in German scientific literature, although in its 400 odd pages it is clearly unable to do justice to every phase of its subject. There is much that can be said in favour of the German method of issuing ponderous Handbücher to which one can turn for information, but in the opinion of the reviewer, this system is not without its defects. The alternative, that of publishing a series of monographs, each restricted

to the consideration of some particular aspect of the main subject, is fast becoming the form adopted by the English-speaking peoples for the presentation of their scientific work. Such a method permits greater attention to detail, a more elastic style, and, as knowledge increases, more easy revision and correction. It must be admitted that "Die Wollkunde" falls into neither class. Its range is too great for the monograph, less exhaustive than is required by the Handbuch, nevertheless it presents the reader with a good introduction to the study of wool.

The first 120 pages—rather more than one quarter of the book—is devoted to histological considerations, and is admirable. Then follow five shorter sections dealing with such physical properties of wool as fineness, uniformity, length of staple, crimp, elasticity, tensile strength, optical properties, and hygroscopicity. Here the survey is less complete, although it is gratifying to see that such questions as the influence on a character such as fineness of variations in the physiological state of an animal, in climate, general nutrition, and the effect upon fineness, of age, sex, heavy or chalky pasture land, cross-breeding, and so on, are dealt with carefully and systematically. With regard to the most desirable staple length, it is interesting to note that the authors have, on page 244, examined the economic possibility of shearing more than once in the twelve months, but decide, definitely, in favour of the existing practice of a single shear.

The section entitled "The Chemistry of Wool" is of little real use. It would have been better to omit it altogether and enlarge the physical section or bring both up to the same level. The two concluding sections deal with the fleece, considered as a unit, and with the main types of sheep's wool and the races which yield them.

Despite the criticisms noted above, the book is undoubtedly one which should be in the hands of anyone concerned with the scientific study of wool, and can be recommended as a useful work of reference. Since reference is essentially the purpose for which it was designed, it is regrettable that the compilers have provided an inadequate subject index and completely omitted an author index. C.R.

Recovery and Use of Industrial Wastes. By J. B. C Kershaw. Published by Ernest Benn Ltd., London. (xx + 212 pp.)

This book is a survey of the general state of affairs with regard to the disposal or utilisation of wastes from manufacturing industries. The comprehensive nature of the survey is indicated by the chapter headings—

I—Introduction; II—Chemical Wastes; III—Engineering Shop Wastes; IV—Foundry and Metallurgical Wastes; V—Mining and Mineral Wastes; VI—Municipal and Domestic Wastes; VII—Paper-pulp and Paper-mill Wastes; VIII—Sugar and Sugar-beet Wastes, IX—Tannery and Leather Trade Wastes; X—Food and Stockyard Wastes, XI—Rubber Manufacturing Wastes; XII—Wool Scouring, Wood Working Wastes, and Miscellaneous Wastes. Each chapter is followed by a list of references and name and subject indexes are provided. Notes on some of the portions of the book which concern the pollution of water in the textile and allied industries follow—

Chemical Wastes—Acids in drainage water may be concentrated by evaporation. Methods for the separation of an emulsified oil from water by physical means and by removing the emulsifying agent, and processes for the recovery of ammonia in waste liquors from the manufacture of artificial silk, are described. The importance of space for settling ponds in the case of chemical or other works producing large quantities of liquid wastes is emphasised.

Foundry and Metallurgical Wastes—Acid waste liquors from the pickling tanks must be treated before discharge into streams or sewers. The method varies according to the use of sulphuric or hydrochloric acid as the pickling agent.

Paper-pulp and Paper-mill Wastes—From the sulphite process the volume of liquor is very large and dilute so that the cost of concentration—always an important factor—is exceptionally high. The valuable organic contents are usually disregarded and screening, liming, and precipitation with ferric chloride used to obtain a safe effluent for discharge into streams. Abstracts are given of recent papers and patents relating to improvements in the methods of dealing with these wastes.

Wool Scouring and Wood Working Wastes—With wool scouring wastes the difficulties are usually due to the presence of fats in the form of an emulsion which

is only partly saponifiable by ordinary methods. Liberating the fats by hydrochloric acid as a scum and running off the liquor gives a low fat recovery and wastes all the potash. Special attention is drawn to de Raeve's method of treatment with lime in conjunction with chlorine gas. Another method is based upon concentration by evaporation. Petrol and trichlorethylene have been proved the most satisfactory agents for the extraction of fats by solvents.

The book is well illustrated, and well-produced, and should be very welcome. T.

Cotton Spinning Notes and Calculations. Dobson & Barlow Ltd., Bolton. (200 pp.)

This compact little book, pocket size, comprises a useful collection of data for all engaged in cotton spinning. In an introductory note it is stated that the work is the outcome of constant requests for details and information relating to cotton spinning machinery. Over twenty years ago the firm issued a similar publication known as "The Students' Calculation Book," which proved popular amongst cotton spinning students, managers, overlookers, and carders. No doubt many will be glad to have the new edition. T.

The Application of Science to Crop-production. By A. & G. L. C. Howard. Published by Humphrey Milford, Oxford University Press, Amen House, Warwick Square, London, E.C.4. (82 pp., price 9s.)

This is the record of an experiment carried out at the Institute of Plant Industry, Indore. In Chapter I is described the origin of the Indore Institute as a natural sequel to that at Pusa, together with the history of the gradual carrying out of the idea of having a central institution for the study of actual crop production, with less fragmentation of the factors therein concerned among the various ancillary sciences. The plant yielding the crop must be studied in relation to the soil, the conditions of village agriculture, the economic uses, etc. Chapter II goes on to describe the Institute itself, and its layout; it covers 300 acres. Chapter III deals with investigations on cotton, which form the chief line of work, as the place owes its origin to the grants made by the Indian Central Cotton Committee. The programme falls into three groups—(1) The investigation of fundamental questions; the results of which apply to the whole of the cotton work in progress in India. (2) Genetics, including the improvement of the kinds of cotton now grown in Central India and Rajputana under dry and irrigated conditions. (3) Improvements in the agronomy of cotton. A collection of unit species is in process of formation, and a careful study of their root systems has already led to the explanation of facts hitherto not properly understood in the success or failure of cotton under various conditions. A preliminary survey of the root-systems of the Indian cottons had been made, with a view to discovering the general differences in type, and the effect of factors like soil-aeration or water-logging upon root development. This work already seems to indicate the reasons for the success of *roseum* cottons and failure of Americans on black cotton soils. Variety improvement also is well under way. Chapter IV deals with improvements in the agronomy of cotton. It is considered that so far as is necessarily the case in introducing improvement among a naturally conservative agricultural population, the line of least resistance—the introduction of obvious improvements like better varieties—has been taken, but that now other things may begin to receive attention, future work being a well-balanced combination of agronomy and genetics with soil science. An account is then given of the various factors limiting production upon black soil, and the measures that can be taken. Such factors are the growth of perennial grasses and soil erosion, in which matters the work done is of particular interest at the present time. Chapter V discusses further agricultural improvements, such as in well-irrigation, cattle, implements, machinery, etc. Chapter VI deals with liason between the Institute and its supporters. In Chapter VII the important subject of the organisation of agricultural research is dealt with, this article forming a very important contribution to the subject from two workers who have themselves done brilliant work. The difficulties involved in the present system of "long range" and "local" research stations are pointed out, and a division into "research" and "demonstration" stations is suggested as preferable. It is upon this conception that Indore is being organised. "Better men are needed, not more machinery," is the summing up; "the man is everything, the organisation a minor matter." No one interested in agricultural progress should leave this book unread. J.C.W.

THE JOURNAL OF THE TEXTILE INSTITUTE

Vol. XXI FEBRUARY 1930 No. 2

PROCEEDINGS

Lancashire Section

Meeting at the Institute, Manchester, on Friday, 6th December 1929, Mr. W. T. Boothman in the chair.

HIGH DRAFTING*

By W. A. Walsh
(Messrs Howard & Bullough Ltd., Accrington)

INTRODUCTION

As you are aware, there are many "high draft" systems and textile machinists, like all other manufacturers, have to supply what their customers demand. Consequently, if a particular customer is persuaded by the inventor, or is the inventor himself of a system which he considers the best, it naturally follows that a licence has to be arranged to supply that particular system. In addition to supplying several such systems, most textile machinists have also to be in a position to offer to customers an arrangement which will justify the extra cost entailed and give good results, so as to bring forward repeat orders.

There are no fixed dividing lines determining where ordinary drafts finish or higher drafts commence. It is the arrangement provided for drafting rather than the amount of draft used which constitutes the features known as "high drafting." The term "high draft," like that of artificial silk, is a misnomer, and a better description is "through drafting." With the ordinary 3-roller arrangement, a much higher draft, say 15 or more, can be exerted on long cottons and fine roving, as against a draft of about half that amount on short cottons and coarse roving, but the larger draft, under the first conditions, does not necessarily imply "high drafting."

The object, then, of "high drafting" arrangements is to extend the control so as to include the maximum number of short fibres whilst allowing the longer fibres to be pulled through, and as a result of the extended control, higher drafts can be used. This is illustrated by Plate I. Herein

Fig. 1 shows the usual 3-line roller ring frame with bottom rollers 1 in., ⅞ in., 1 in. diameter as used for cottons of about 1¼ in. staple. For this cotton the usual setting between the centres of front and second bottom roller is 1$\frac{5}{16}$ in.

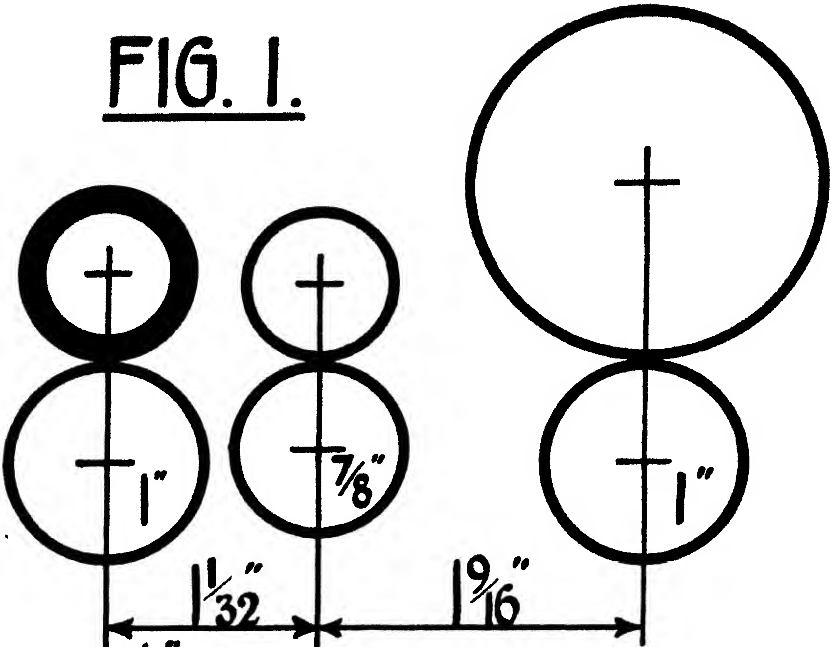
Fig. 2 shows graphically the percentage of pulled through, controlled, and floating fibres.

Similar particulars are shown on this plate in Figs. 3, 4, 5, and 6. Figs. 3 and 4 relate to 3-line roller ring frame with smaller diameter middle bottom rollers than Figs. 1 and 2, whilst Figs. 5 and 6 relate to 4-line roller ring frames.

The use of "high drafts" with the usual 3-roller system presents greater difficulties with a coarse roving and short cotton than with a fine roving and long cottons, on account of the closer settings necessary, in the attempt to extend the control to the shorter fibres. The difficulties arising with ordinary roller arrangements have led to the introduction of a great number of "high draft" arrangements, which, whilst allowing a close setting to maintain control, are designed to allow the long fibres to be pulled through.

* In the unavoidable absence of Mr. Walsh, this paper was read by Mr. Wilson.

FIG. 1.


1"
7/8"
1"
1 1/32"
1 9/16"

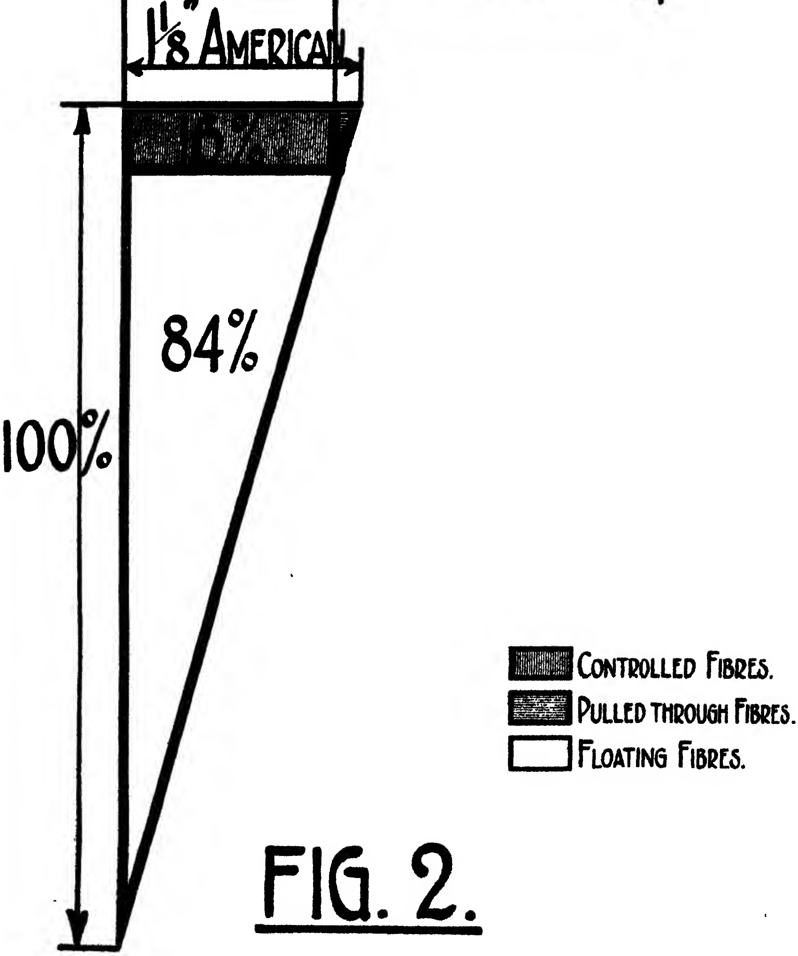

1 1/8" American
16%
84%
100%
Controlled Fibres.
Pulled through Fibres.
Floating Fibres.

FIG. 2.

EARLY INVENTIONS

The record of inventions relating to the textile industry taken out by Englishmen, and particularly Lancashire men, is a record of which we have every reason to be proud. In this record, if a diligent enough search be made, it will usually be found that most of the modern inventions, especially those taken out on the Continent, have been anticipated.

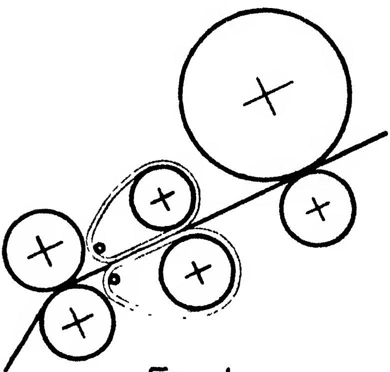


FIG. 1.

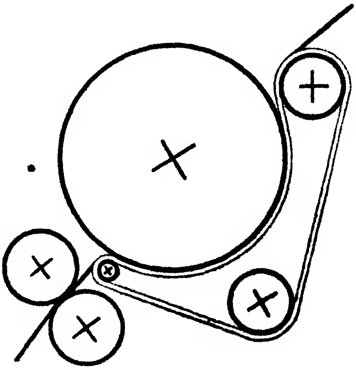


FIG. 2.

FIG. 3.

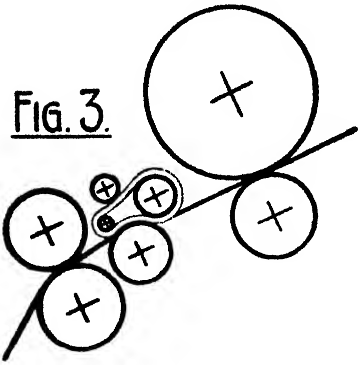


FIG. 4.

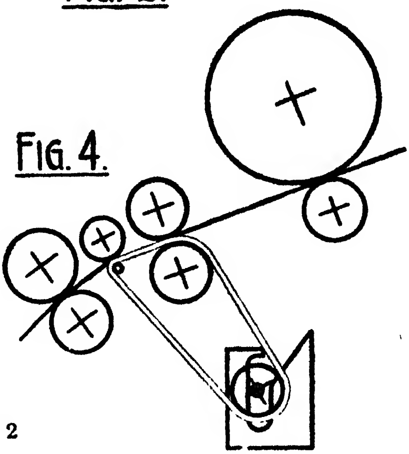


PLATE 2

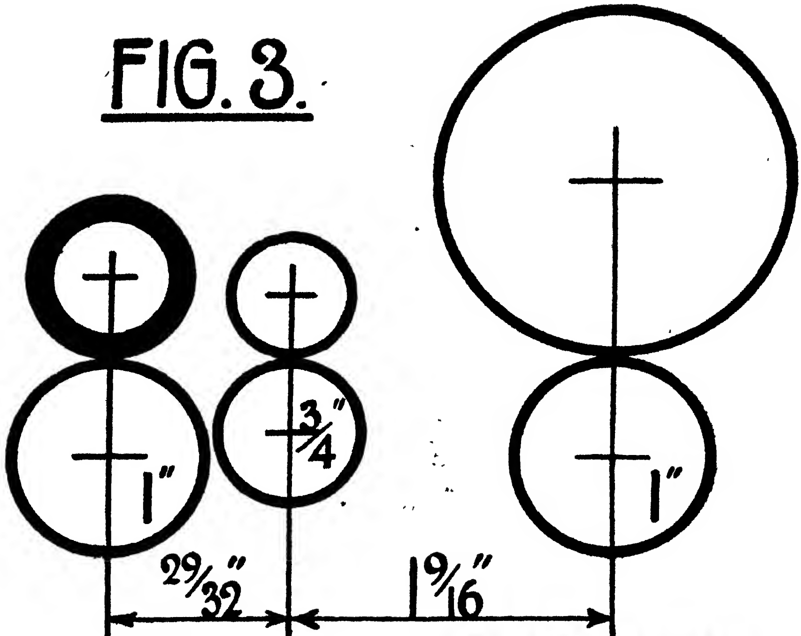
There is filed in the English Patent Office a patent taken out in 1823 by Philip Chell relating to drafting arrangements which clearly defines the "pull through" idea. One passage from it reads—

> The introduction of the endless revolving straps to support and carry forward the material to be operated upon between the rollers, and which I likewise believe to be entirely new.

This invention over a hundred years ago clearly anticipates the idea but not the present arrangement of the Casablanca system.

Whilst "high draft" arrangements on a limited scale have been in use for upwards of 30 years, the advent of the Casablanca system gave the impetus to other systems, and the birth of the present vogue may be stated to be about 1912.

FIG. 3.



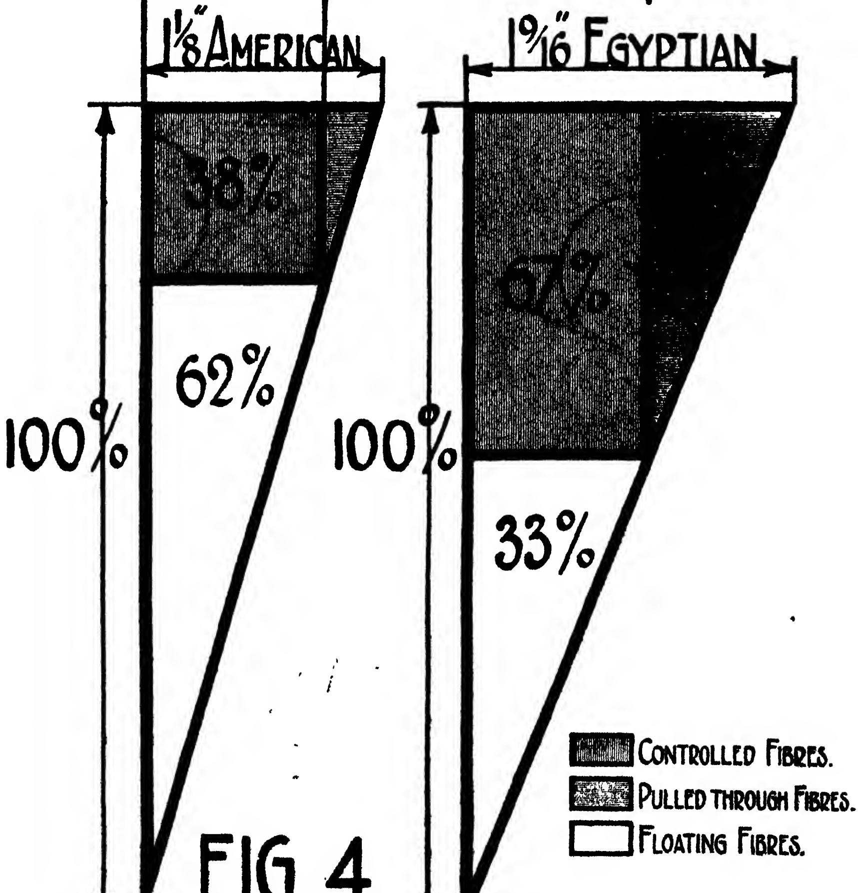


FIG. 4.

PLATE 1

THE PRINCIPAL MODERN SYSTEMS

The various arrangements which are in use can be divided into three main systems—

(1) *Tape systems.*

(2) *Three-roller arrangements with various types and disposition of top rollers.*

(3) *Four-roller arrangements with various types of second top rollers, and variations to the weighting of the third top rollers.*

Three- or four-roller arrangements are classified by the number of Bottom rollers used without reference to the Top rollers. These are illustrated by Plates Nos. 2, 3, and 4.

Plate 2 shows the tape arrangements.

Plate 3 shows the 3-roller arrangements, and also a special arrangement with bottom rollers having a "bridge" between. See Fig. 7.

Plate 4 shows the 4-roller arrangements.

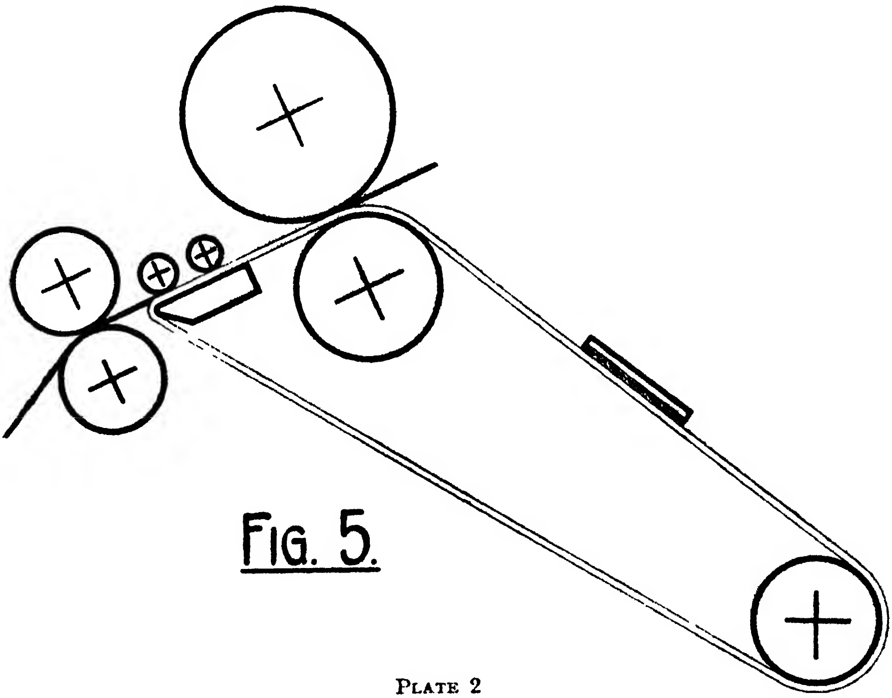
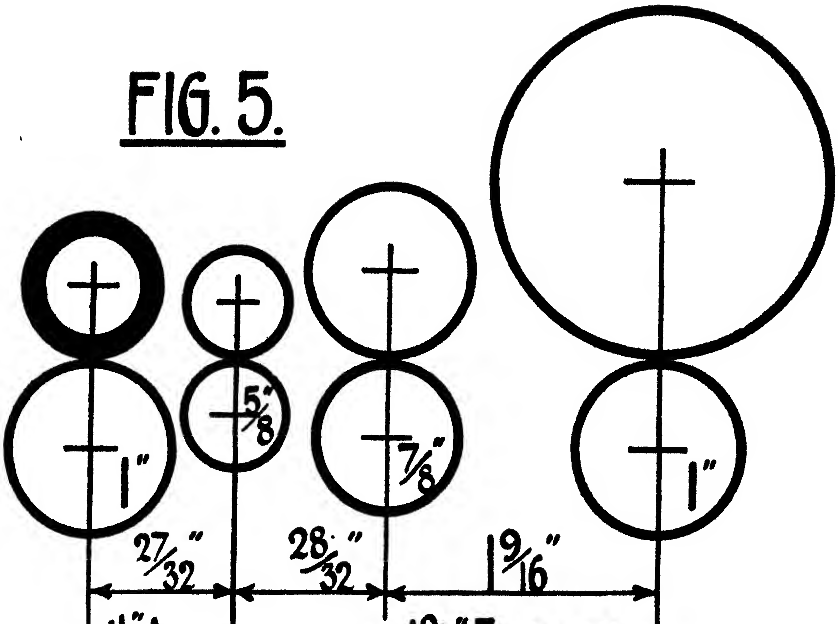


FIG. 5.

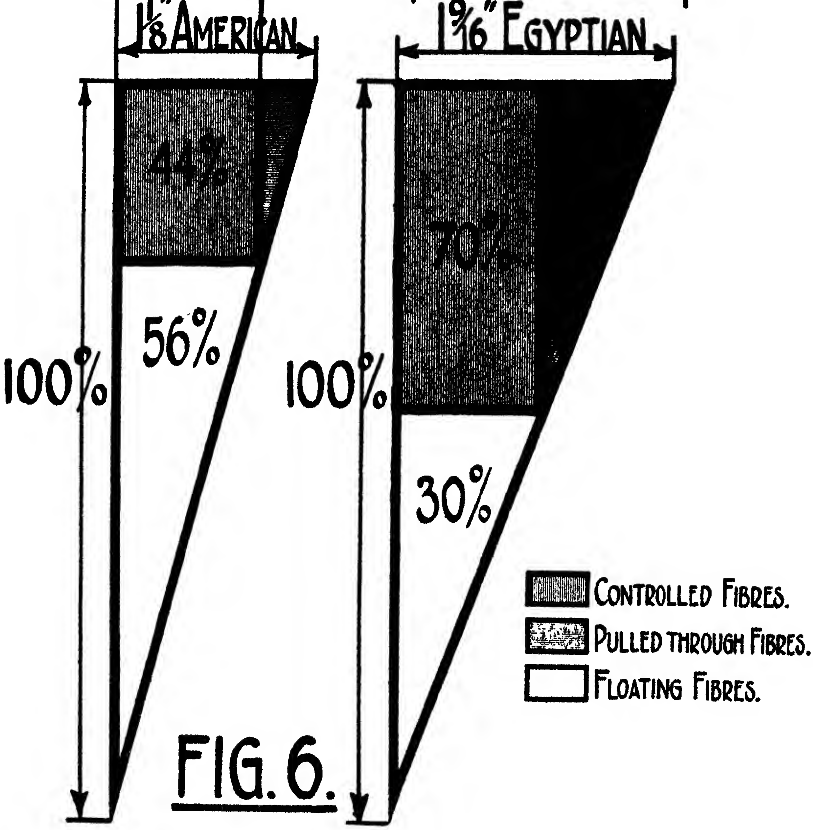
PLATE 2

You will note all these arrangements are devised to give a close setting to the front pair of rollers, and at the same time to give control in the drafting field and to allow of a pull through or continuous drafting. Theoretically, the Casablanca system attains this continuity of drafting, but in the opinion of many the tape systems have serious disadvantages. The first experiments with the Casablanca system were made on our frames, and in the year 1913 we were asked to take over the licence for this system. We did not do so, as we already had attained some measure of success with "high draft" on 3-roller ring frames, using a light second top roller of 3 oz. weight.

FIG. 5.



1"
5/8"
7/8"
1"
27/32"
28/32"
1 9/16"



1 1/8" AMERICAN
1 9/16" EGYPTIAN
44%
56%
100%
70%
30%
100%
CONTROLLED FIBRES.
PULLED THROUGH FIBRES.
FLOATING FIBRES.

FIG. 6.

Many thousands of spindles were supplied by us as far back as the year 1911 to the particulars shown on Plate 5, Fig. 1, namely, 1 $\frac{5}{32}$ in., $\frac{7}{8}$ in., 1 $\frac{5}{32}$ in. bottom rollers; with top rollers 1 $\frac{1}{8}$ in. uncovered front, $\frac{3}{4}$ in. second, and 2 in. back. You will note the second bottom roller is of large diameter, as the cotton used for the counts to be spun allowed for a wide setting.

We were also making 3-roller arrangements in 1904, as shown by Plate 5, Fig. 2, having bottom rollers $\frac{3}{4}$ in., $\frac{5}{8}$ in., and $\frac{3}{4}$ in., with top rollers $\frac{15}{16}$ in. uncovered, $\frac{5}{8}$ in., and 2 in., whilst we made 4-roller arrangements in 1895 having bottom rollers $\frac{3}{4}$ in., $\frac{3}{4}$ in., $\frac{3}{4}$ in., and $\frac{31}{32}$ in., with top rollers $\frac{11}{16}$ in. uncovered, $\frac{5}{8}$ in., $\frac{5}{8}$ in., and 1 $\frac{3}{4}$ in., as shown by Plate 5, Fig. 3.

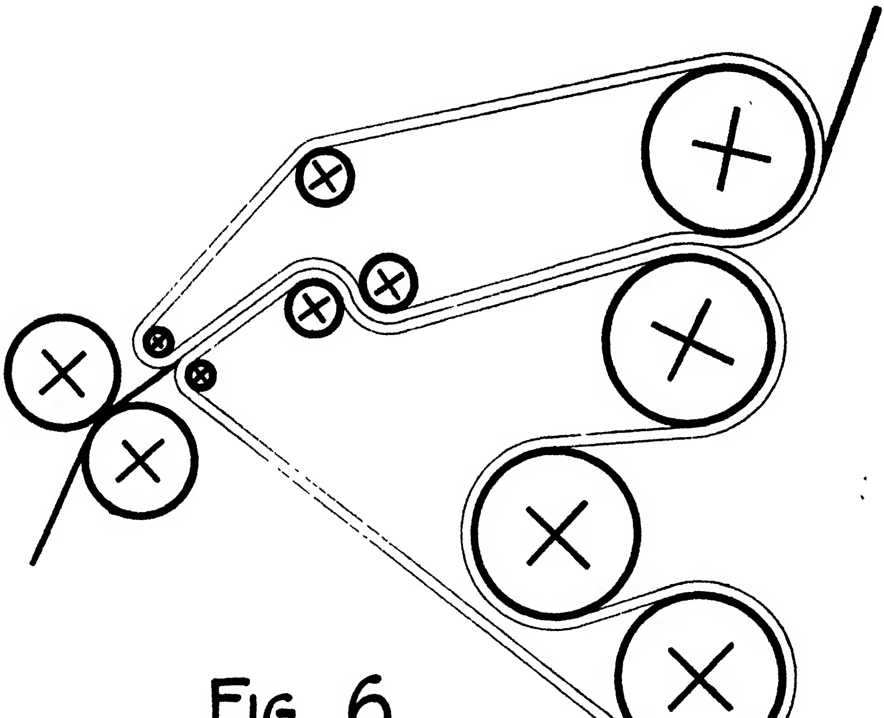


FIG. 6.

PLATE 2

Whilst the 3-roller arrangement with small diameter second bottom roller and light second top roller is the simplest "high draft" arrangement in use, it has the following defects—

(1) If the back top roller is lifted to insert a new roving, the adjacent roving will be out of control and will run through without being drafted.

(2) The drafting takes place between the front and back pairs of rollers, and no intermediate or break draft is present to break down the twist in the roving to prepare it before it passes to the drafting field.

In the 3-roller arrangements, with two top rollers on the middle bottom roller as shown by Plate 3, Figs. 2, 5, and 6, an attempt has been made to overcome the defects of the simple 3-roller arrangement. It can be taken as a desirable feature

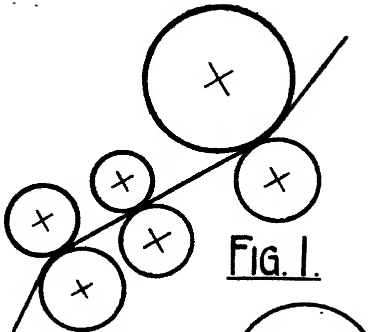


Fig. 1.

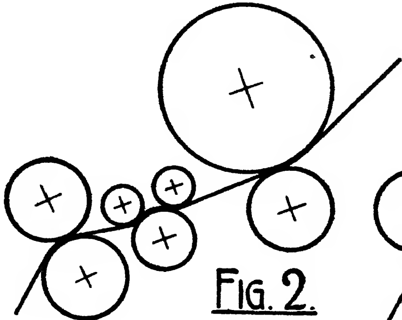


Fig. 2.

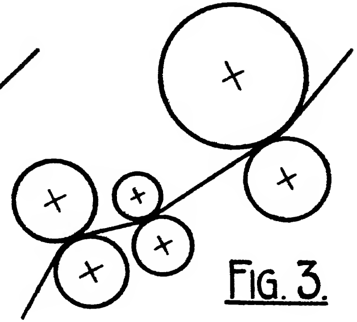


Fig. 3.

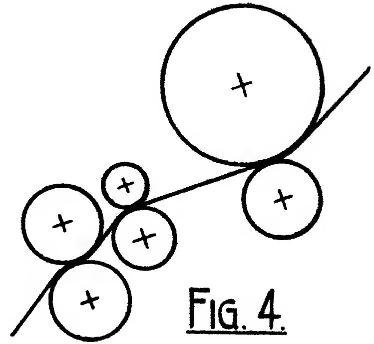


Fig. 4.

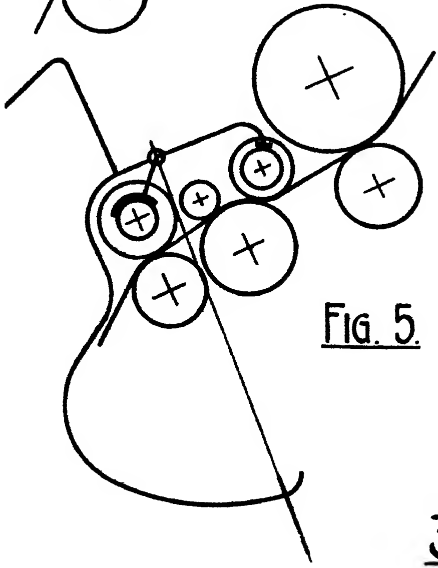


Fig. 5.

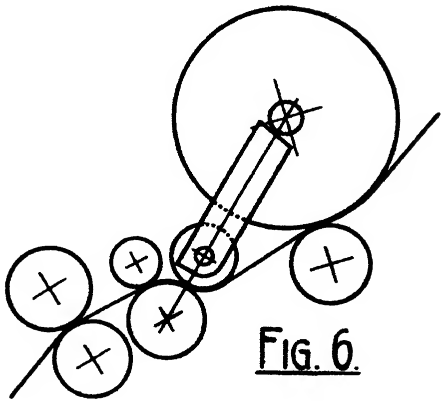


Fig. 6.

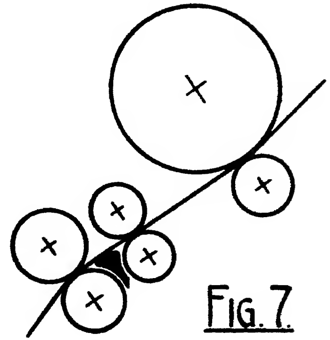


Fig. 7.

3-Roller Arrangements.

Plate 3

that the path of the roving through the rollers should be in a straight line, and the 3-roller arrangements with two top rollers on the middle bottom roller do not fulfil this condition.

In the 4-roller arrangements, the main point of difference, apart from the many types of second top rollers in use, is the method of weighting the third top roller. On Plate 4, Fig. 2, the third top roller is weighted by a saddle extended from the weight hook on the front top roller.

SUCCESSFUL HIGH DRAFTING

The primary conditions to be attained in a successful "high draft" system are—

(1) A close setting where the main drafting takes place

(2) A control of the fibres in the roving, which allows of the minimum number of floating fibres.

Secondary attributes desirable in the use of a "high draft" system are—

(3) Fifty per cent. or more increased draft.

(4) A resulting yarn as strong and level or even stronger than the yarn from a normal draft machine.

(5) The minimum additional work added to the operatives

(6) Production from the ring frame at least equal to that from a normal draft machine.

(7) No additional expense involved in maintaining the "high draft" roller arrangement.

(8) It naturally follows that the arrangement must be of the simplest form to give conditions (5), (6), and (7).

Much experimental work has been done by us in trying various systems, and after prolonged experience under mill conditions, I am convinced that, generally speaking the 4-line system shown by Plate 6 will give the closest approximation to the results desired. I wish briefly to draw your attention to the following features of this system—

The break draft between third and back roller is 1·28.

The break draft between second and third roller is 1·54.

These are calculated drafts, and not fully obtainable, because the second and third top rollers are self-weighted. The third line of rollers is necessary to assist in the correct working of the second pair of rollers, and they are set beyond the point where the main drafting ceases. The third top roller must exert a pressure to grip firmly the roving, and generally speaking a self-weighted roller gives the best results, but for very coarse and hard-twisted rovings additional pressure to the weight of the roller may be an advantage.

You will note there are two traverse rods which are always applied whether single or double roving is used. This is necessary, as the distance from front roller to back traverse rod is greater with the 4-roller system than with the 3-roller system, and the additional middle traverse rod reduces the "lag" of the traverse on the front roller which would obtain without it.

The drive to the traverse motion from the back roller is speeded up to compensate for the lower speed of the back roller, due to the higher draft. The traverse motion must be in perfect condition, and the total length of traverse should be, say, ⅛ in. larger than normal, owing to the greater distance of the traverse rods from the front roller.

Loose-boss front top rollers are advised with roller cloths thicker than usual to give greater cushioning on the front bottom roller. The front top roller should be made as large as possible; for a 1 in. diameter front bottom roller it should not be less than 15/16 in. diameter, uncovered, or, say, 1⅛ in. diameter covered. It is better to make this roller 1/16 in. too big than 1/16 in. too little. If it is too small, trouble is experienced with roller laps.

The roving should have the minimum amount of twist, which necessitates more attention being given to the various parts of the creel.

There are two under clearers and two top clearers.

The diameter of rollers for cottons of different staple lengths with the settings usually adopted are shown in Table 1.

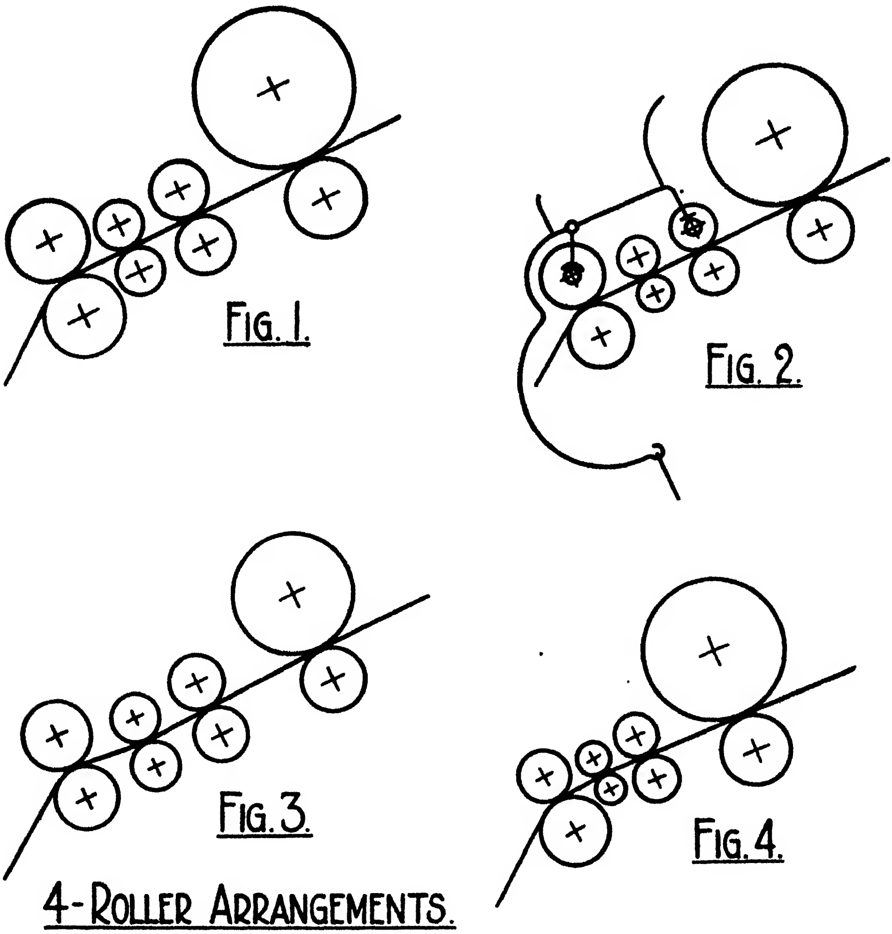


Plate 4

Table I

(*a*) Rollers and Settings for Indian and American Cotton up to $1\frac{1}{16}$ in. Staple.

	Bottom Rollers	Top Rollers	Settings
1st ..	$\frac{3}{4}$ in or $\frac{7}{8}$ in ..	$\frac{11}{16}$ in. or $\frac{13}{16}$ in uncovered ...	$\frac{25}{32}$ in. adjustable
2nd ...	$\frac{5}{8}$ in ...	$\frac{5}{8}$ in (variable) ...	$\frac{26}{32}$ in. adjustable
3rd ...	$\frac{3}{4}$ in. ...	$\frac{7}{8}$ in. ...	$1\frac{9}{16}$ in fixed
4th ...	$\frac{7}{8}$ in. ...	2 in. ...	

(*b*) Rollers and Settings for American and Egyptian Cotton for Staple $1\frac{1}{16}$ in. and Upwards.

	Bottom Rollers	Top Rollers	Settings
1st ...	$\frac{7}{8}$ in or 1 in. ...	$\frac{13}{16}$ in or $\frac{15}{16}$ in. uncovered ...	$\frac{27}{32}$ in. adjustable
2nd ..	$\frac{5}{8}$ in. ...	$\frac{5}{8}$ in. (variable) ...	$\frac{28}{32}$ in. adjustable
3rd ...	$\frac{7}{8}$ in. ...	1 in. ...	$1\frac{9}{16}$ in fixed
4th ...	1 in. ...	2 in. ...	

The combination of a close setting between the first and second pairs of rollers and a light second top roller is applicable to the spinning of both coarse and fine counts, but for the coarser counts a stronger yarn will be obtained with a second top roller heavier than that suitable for the fine counts. The limitation of weight of the second top roller in combination with close setting is that at which "crackers" will be found. No rule can be stated which is applicable to all conditions, but for coarse and medium counts a highly polished solid cast-iron roller with round-ended tapered nipples is generally used, and for counts of 36's and upwards, a light second top roller made from a steel tube with cast-iron ends and tapered nipples is used. The second top roller pivots are tapered with the end slightly rounded to ensure free rotation.

Defects of 4-Roller System

There is more fly deposited on the weight hooks and roller beam than with the normal draft machines, and this, in conjunction with the extra line of top rollers and bottom rollers, and extra top and bottom clearers, means a little more work for the operatives.

In England, operatives have been paid, in some cases, a little extra, varying from 1½d. to 3d. per 100 spindles per week.

Unless care is exercised in making the piecings in the roving, there is a tendency to produce more "slubs" on the 4-roller system than on the 3-roller system. This latter defect may be overcome to a considerable extent if the spinners will twist in the rear end after putting in a new roving bobbin, otherwise the tail end is not drafted.

For yarn to be as free from "slubs" as possible, the best way to run in the end from a new roving bobbin is to present it to the back rollers, and just after it passes between these, to break off the old roving just behind the back traverse rod. The short length of double roving, assuming we are considering single roving in the creel, will then be ejected from the front roller, the end will break down, and will have to be pieced up at the front.

Advantages of the 4-Roller System

The cotton used and the yarn to be produced from same are factors which prohibit one from saying the 4-roller system is beneficial in all cases. Generally speaking, however, especially for medium and higher counts, it can be said that the 4-roller system will allow for 50% higher drafts to be used, and the resulting yarn to be as good as regards strength and regularity as the yarn produced on the ordinary 3-roller system with the lower drafts using the same cotton in both cases.

Alternatively, by using a "high draft" arrangement at the ring frames, and using the normal drafts, it is possible to spin a cheaper cotton than with the ordinary draft arrangement, and to produce as good a yarn. By this method, for some counts a bigger saving may be effected in the raw material than would be effected in wages by increasing the draft at the ring frames.

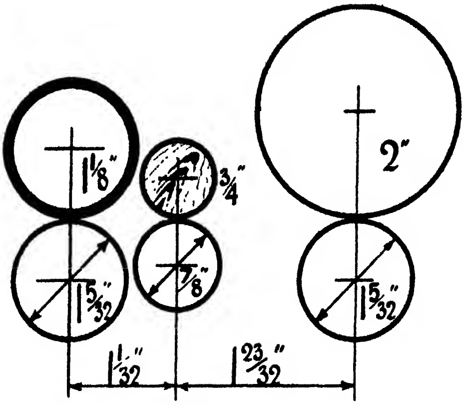
I will now give some of the results which are being obtained with the 4-roller system.

My first example is that of a mill with the usual 3-roller ring frames spinning 23's from 4·6 hank roving, using double roving at the ring frames, which had therefore a draft of 10, and three passages of speed frames were in use.

The installation on 4·6 hank roving had 41,160 spindles, which produced 69,580 lb. of yarn per week.

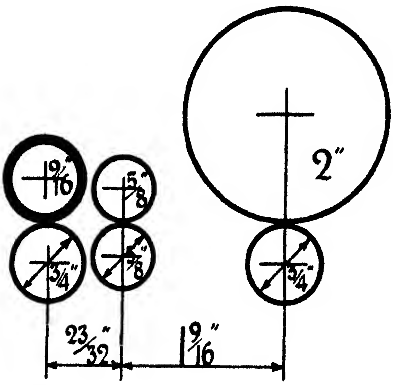
The wage bill to produce the roving, including the men unloading cotton to the finished roving, but omitting the carder and undercarder, was £225 4s. 10d. This gives ·777d. per lb. of roving produced.

The wage bill in the spinning-room, omitting the spinning master and assistant spinning master, was £174 5s. 4d. This gives ·6011d. per lb. of yarn produced.



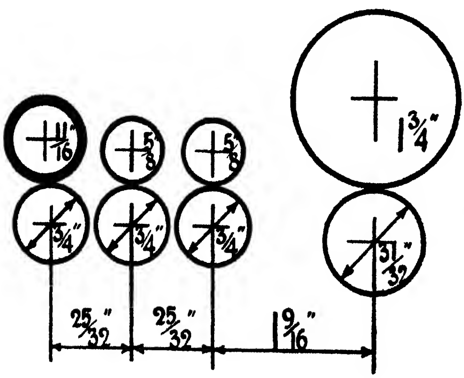
MIDDLE TOP ROLLER.
WOOD.
WEIGHT 2·99 OUNCES.

FIG 1.



MIDDLE TOP ROLLER.
CAST IRON.
WEIGHT 6·07 OUNCES.

FIG. 2.



SECOND TOP ROLLER.
CAST IRON.
WEIGHT 5·54 OUNCES.

FIG. 3.

The total wage cost was therefore 1·3781d. per lb. of yarn produced.

Trials were made with the 4-roller system, and it was proved that higher drafts could be used at the ring frames without impairing the strength and regularity of the yarn. It was decided in the first instance to reduce the hank roving from 4·6 to 3·4, which increased the draft at the ring frames from 10 to 13·53. Three passages of speed frames were retained.

H. & B's Standard Arrangement of 4-Roller High Drafting.

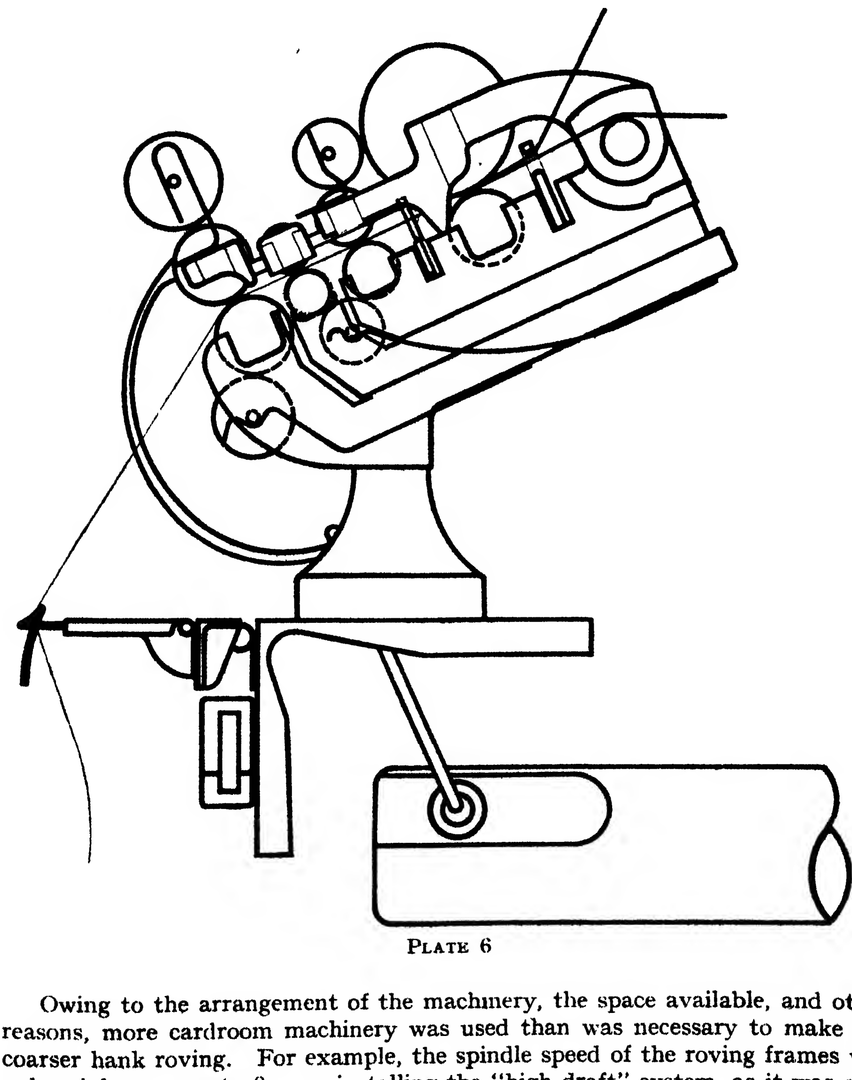


Plate 6

Owing to the arrangement of the machinery, the space available, and other reasons, more cardroom machinery was used than was necessary to make the coarser hank roving. For example, the spindle speed of the roving frames was reduced from 1050 to 850 on installing the "high draft" system, as it was considered that two frames on 3·4 hank could not be satisfactorily followed with a spindle speed of 1050 r.p.m., and since the frames were available, there was no point in retaining the higher speed.

Ten thousand and eighty more ring spindles were added, and it was then decided to increase the number of preparations from 10 to 12. This involved the addition of 14 cards, two sets of drawing and two slubbing frames. The number of intermediate frames was kept the same, and the number of roving frames reduced from 56 to 40.

As will be seen later, the first installation only partially utilised the economies which could be made, but even so, the wage bill to produce the roving is practically the same, viz., £226 8s. 7d. for "high draft" against £225 4s. 10d. for ordinary draft.

The 10,080 extra ring spindles increased the weight of yarn produced from 69,580 lb. to 86,620 lb. per week. This gives ·6273d. per lb. of roving produced.

The wage bill in the spinning-room is £221 4s. 8d., which on the production of 86,620 lb. of yarn, gives ·6129d. per lb. of yarn produced. It will be noted that this is slightly higher than with the ordinary draft. This is accounted for by the extra wages to be paid to the spinners on the "high draft" system. The total wage cost is therefore 1·2402d. per lb. of yarn produced, as against 1·3781d. per lb.

Further trials were made with increased draft on the 4-roller ring frames, and after exhaustive tests it was proved beyond question that yarn could be spun from a coarser hank roving and omitting the intermediate frames, which was equal in strength and regularity to the yarn spun on the ordinary 3-roller frames.

An installation of 43,680 spindles, producing 73,840 lb. of yarn per week was installed, omitting intermediate frames, and a 2·76 hank roving with 16·66 of a draft in the ring frame was adopted.

With this latest addition, the wage bill to produce the roving, including the men unloading cotton to the finished roving, but omitting carder and under-carder, is £168 8s. 4d. This gives ·541d. per lb. of roving produced.

The wage bill in the spinning-room, omitting spinning master and assistant spinning master, is £181 6s. 8d. This gives ·584d. per lb. of yarn produced.

The total wage cost is therefore 1·125d. per lb. of yarn produced.

When this installation had been working for some time, it was found that the yarn was slightly stronger than from the ordinary 3-roller system or the 4-roller system, using three passages of speed frames. The conclusion was that this was due to the increased humidity obtained in the latest installation.

The results are summarised in Table II.

Table II

	Ordinary 3-Roller System		4-Roller High Drafting System 1st Installation		4-Roller High Drafting System 2nd Installation	
		Drafts		Drafts		Drafts
Hank Draw	·155		·17		·166	
Hank Slubb.	·64	4·13	·72	4·23	·86	5·18
Hank Inter.	1·50	4·17	1·56	4·33		
Hank Roving	4·60	6·13	3·40	4·36	2·76	6·42
Ring counts spun, 23's		10·00		13·53		16·66
	(Double at Inter. Roving and Ring Frames)		Double at Inter. Roving and Ring Frames.		(Double at Roving and Ring Frames)	
	Wage cost per lb. of yarn up to roving, ·777d.		Wage cost per lb. of yarn up to roving, ·6273d.		Wage cost per lb. of yarn up to roving, ·541d.	
	Ditto for spinning, ·6011d		Ditto for spinning, ·6129d.		Ditto for spinning, ·584d.	
	Total wage costs in blowroom, cardroom and spinning-room 1·3781		Total wage costs in blowroom, cardroom and spinning-room 1·2402d.		Total wage costs in blowroom, cardroom and spinning-room 1·125d.	

It will be seen that the difference in wage costs from men unloading cotton to yarn on bobbins, between ordinary 3-roller system and second installation 4-roller high draft system, is 1·3781 less 1·125 = ·2531d. per lb. of yarn. In the second installation on the "high draft" system, there were exactly 50% fewer speed frames than in the ordinary 3-roller system. This resulted in a reduction in—

(1) *Productive expenses.*

(2) *Establishment expenses.*

(3) *Financial expenses.*

With regard to productive expenses, the largest saving was due to the reduction in power, this being approximately ·04d. per lb. of yarn. Other items under productive expenses, such as oil, leather, ropes, bands, brushes, repairs, etc., are ignored.

The second installation on "high draft" cost approximately £8,000 less in machinery, and the floor space occupied was considerably reduced when compared with an installation on ordinary 3-roller drafting.

The Establishment expenses, such as taxes, rates, rents, and insurance, and the Financial expenses, such as interest and depreciation, I do not propose to elaborate, but the saving on these, along with the saving in production expenses and the reduction in wage costs of ·2531d. per lb. of yarn, have resulted in a total saving of approximately ·5d. per lb. of yarn produced, which on a basis of a production of 73,840 lb. of yarn per week, means a saving of approximately £150 per week.

The foregoing data have generously been given to us by one of our customers for the purpose of this paper; it is a case, however, where low counts are being spun from much better cottons than are usually used for such counts, but the data are comparative, and will therefore, I trust, be of interest.

The next example embodies data obtained from one of our customers in India. In this case the counts spun are 20's, from Indian cotton of staple length —·9 in. On the ordinary 3-roller ring frames, a 2-hank single roving requiring a draft of 10 was used.

Our 4-roller high draft arrangement was installed, and 1·3 hank intermediate requiring a draft of 15·4 was used.

The yarn spun on the 4-roller arrangement is 5 to 6 lb. per lea stronger than that spun on the ordinary 3-roller system.

Over 10,000 additional ring spindles were added without any increase to the number of speed frames, the additional cards being available.

The actual spindle speed is 10,000 r.p.m.

The turns per inch, 17·2.

Diameter of ring, 1⅝ in.

Production 8¼ ozs. per spindle in 10 hours.

This case is not typical of the results usually obtained on 20's in Lancashire. The yarns spun in India, either on ordinary 3-roller or 4-roller high -draft ring frames, would not usually be considered satisfactory in Lancashire. No definite statement can be made which is true for all cases on these counts, as so much depends on the cotton used, and in many cases it is better to only slightly reduce the normal hank roving and retain three passages of speed frames, and to use the "high draft" 4-roller arrangement at the ring frames with a draft only slightly increased. By the adoption of this method, a cheaper cotton can be used to give a yarn equal in strength and regularity to that spun on the ordinary 3-roller ring frames.

Further examples from our Continental customers using our 4-roller "high draft" arrangement may be of interest.

Table III

Hank Intermediate or Roving	Counts	Drafts	Remarks
(1) 1·75 Intermediate (single)	21 ...	11·4 ...	Yarn is as strong as formerly obtained from 3-hank roving. Second top roller, cast-iron. Weight 2,250 grains.
(2) 4·6 Roving (double) ...	38's and 42's ...	16·5 to 18·2 ...	Cotton used (American). Second top roller, steel tube. Weight 1,500 grains.
(3) 4·0 to 5·0 Roving (double) ...	40's and 50's ...	20's ...	Second top roller, steel tube. Weight 1,020 grains.
(4) 5·5 to 6·0 Roving (double) ...	45's to 60's ...	16·3 to 20 ...	Second top roller, steel tube Weight 1,000 grains.

In conclusion, four summaries of machinery, Tables IV, V, VI, and VII, are presented to show the difference between the machinery required for new 40,000 ring spindle mills on 36's and on 70's spun on ordinary 3-roller ring frames and on 4-roller "high draft" ring frames. Whilst many variations to these summaries can be made, they are representative of many installations on these counts.

Machinery on Table V would cost approximately £2,000 less than the machinery in Table IV, and the reduction in cardroom wages would be approximately £19 per week. Machinery in Table VII would cost approximately £3,000 less than the machinery in Table VI, and the reduction in cardroom wages would be approximately £25 per week.

Table IV

	36's Ordinary Draft	Lb.	Draft
1	No. 7 hopper bale opener, 38 in. wide, delivering to mixings		
2	No. 9 hopper feeders, 38 in wide		
2	Openers with 24 in diameter porcupine cylinders, 38 in. wide		
2	Single Crighton openers		
2	Cage exhausters to suit No. 9 hopper feeders	38,483	
2	No. 9 hopper feeders, 38 in wide		
2	Single Buckley opener combined with scutcher and lap machine, 38 in. wide		
3	Single beater finisher scutchers, 38 in wide		
60	Revolving flat cards, 37 in on the wire, 50 in cylinders, 26 in. doffers at 609·3 lb. each of ·14 hank	36,560	
15	Drawing frames with 2 heads of 4 deliveries each = 40 finishing deliveries at 905 lb each of ·14 hank	36,200	
5	Slubbing frames of 100 spindles each = 500 spindles at 71·7 lb. per spindle of ·625 hank	35,850	4·8
10	Intermediate frames of 142 spindles each = 1,420 spindles at 25·0 lb. per spindle of 1·55 hank	35,500	5·1
28	Roving frames of 180 spindles each = 5,040 spindles at 6·97 lb per spindle of 5·0 hank	35,148	5·71
100	Ring frames of 400 spindles each = 40,000 spindles at ·87 lb. per spindle of 36's double roving	34,800	14·4

Table V

	36's High Draft	Lb.	Draft
1	No 7 hopper bale opener, 38 in. wide, delivering to mixings		
2	No. 9 hopper feeders, 38 in. wide		
2	Openers with 24 in. diameter porcupine cylinders, 38 in wide		
2	Single Crighton openers		
2	Cage exhausters to suit No. 9 hopper feeders	38,050	--
2	No. 9 hopper feeders, 38 in. wide		
2	Single Buckley openers, combined with scutcher and lap machines, 38 in. wide		
3	Single beater finisher scutchers, 38 in wide		
60	Revolving flat cards, 37 in. on the wire, 50 in. cylinder, 26 in. doffers at 602·3 lb. each of ·11 hank	36,140	
12	Drawing frames with 2 heads of 4 deliveries each = 32 finishing deliveries at 1,121·2 lb. each of ·11 hank	35,880	
4	Slubbing frames of 86 spindles each = 344 spindles at 103·5 lb. per spindle of ·50 hank	35,622	4·5
6	Intermediate frames of 142 spindles each = 852 spindles at 41·5 lb. per spindle of 1·25 hank	35,382	5·0
16	Roving frames of 180 spindles each = 2,880 spindles at 12·21 lb. per spindle of 3·5 hank	35,164	5·6
100	Ring frames of 400 spindles each = 40,000 spindles at ·87 lb. per spindle of 36's double roving	34,800	20·57

Table VI

70's Ordinary Draft.

		Lb.	Draft
1	No. 7 hopper bale opener, 38 in. wide, delivering to mixings 1 No. 9 hopper feeder, 38 in. wide 1 Single Buckley combined with scutcher and lap machine 2 Single beater finisher scutchers	= 17,630	
40	Revolving flat cards, 37 in. on the wire, 50 in. cylinders, 26 in. doffers at 418·7 lb. each of ·17 hank	= 16,750	
4	Sliver lap machines at 4,162·5 lb. each	= 16,650	
4	Ribbon lap machines at 4,125 lb. each	= 16,500	
24	Combers at 590 lb. each (15% waste)	= 14,150	
12	Drawing frames with 2 heads of 4 deliveries each = 32 finishing deliveries at 437·5 lb. each of ·20 hank	= 14,000	
4	Slubbing frames of 96 spindles each = 384 spindles at 36·0 lb. per spindle of 1·1 hank	= 13,840	5·5
8	Intermediate frames of 142 spindles each = 1,136 spindles at 12·0 lb. per spindle of 3·3 hank	= 13,710	6·0
32	Roving frames of 180 spindles each = 5,760 spindles at 2·35 lb. per spindle of 11·0 hank	= 13,575	6·6
100	Ring frames of 400 spindles each = 40,000 spindles at ·336 lb per spindle of 70's double roving	= 13,440	12·7

Table VII

70's High Draft.

		Lb.	Draft
1	No 7 hopper bale opener, 38 in wide, delivering to mixings 1 No. 9 hopper feeder, 38 in. wide 1 Single Buckley combined with scutcher and lap machine 2 Single beater finisher scutchers	= 17,316	
40	Revolving flat cards, 37 in. on the wire, 50 in cylinders, 26 in. doffers at 411·2 lb each of ·15 hank	= 16,450	
4	Sliver lap machines at 4,087·5 lb. each	= 16,350	
4	Ribbon lap machines at 4,050·0 lb. each	= 16,200	
24	Combers at 579·2 lb. each (15% waste)	= 13,900	
9	Drawing frames with 2 heads of 4 deliveries each = 24 finishing deliveries at 575·4 lb. each of ·15 hank	= 13,810	
3	Slubbing frames of 80 spindles each = 240 spindles at 57·1 lb. per spindle of ·75 hank	= 13,720	5·0
6	Intermediate frames of 142 spindles each = 852 spindles at 15·9 lb. per spindle of 2·2 hank	= 13,625	5·8
18	Roving frames of 180 spindles each = 3,240 spindles at 4·2 lb. per spindle of 7·0 hank	= 13,608	6·3
100	Ring frames of 400 spindles each = 40,000 spindles at ·336 lb. per spindle of 70's double roving	= 13,440	20·0

Yorkshire Section

Special Meeting in the Council Chamber of the Town Hall, Bradford, on Thursday, 9th January 1930, Lieut.-Col. B. Palin Dobson in the chair.

THE LATEST ASPECTS OF RATIONALISATION

The Council Chamber of Bradford Town Hall was almost filled on this occasion, and the importance of the occasion was marked by the presence of the President of the Institute, who presided. Among those on the platform with Col. Dobson were the Lord Mayor of Bradford, Alderman A. H. Rhodes, Sir Donald Horsfall, Mr. Wilfrid Turner, Sir W. E. B. Priestley, Mr. R. G. Bailey, Chairman of the Yorkshire Section, and Mr. C. S. Ickringill, Hon. Secretary of the Section. Introducing the lecturer, Sir Josiah Stamp, the President thanked him for consenting to come to Bradford, and expressed confidence that those present were to be interested and instructed by so eminent a lecturer.

In the course of his speech, Sir Josiah Stamp said that judging by recent comments from influential quarters, a reaction was setting in against the process of rationalisation. Indeed, if by rationalisation we really meant processes which preserved the *status quo*, or which restricted output; if we really meant nothing but mass production, monopolisation, and trustification, then indeed the outlook was serious. Such a trend might be self-protective, but it would inevitably also be nationally destructive. What were the facts? We had a number of industries which for various reasons were in difficulties, and could not market a reasonable proportion of their total productive capacity at prices which would cover their costs. Two methods appeared to offer a solution—one was to utilise devices for keeping up prices, and the other to keep down the costs. True rationalisation, he urged, was a means of reducing costs by greater efficiency. Pure individualism, particularly on a small scale, found a way out of such difficulties by the economic annihilation of the less fit units Though ultimately, no doubt, these less-fit units had to succumb, in their dying struggles they enfeebled the fit and reduced the whole industry to a precarious position. True rationalisation did not seek to defeat or defer economic consequences, but having ascertained the inevitable, sought to bring it about more quickly by definite action Its action was more humane and more certain; the units now going under might not be the least efficient, but merely the weakest financially. Such "selection" was arbitrary, and would be avoided by true rationalisation, which would proceed upon a basis of technical efficiency and the greatest potential good

In the public mind, said the lecturer, rationalisation was confused with quotas, trusts, rings, and tariff walls All these tended to inhibit the action of economic laws But if the term was associated with things which it did not connote, a new term must be found. It was idle to suppose that in the present-day foreign trade small individual units would hold their place against large-scale units It was no good kicking against the facts

Referring to the textile industries, Sir Josiah said the small-scale industrialistic units, the backbone of Victorian progress, depended for continued progress upon supplies of personal capital provided by its abstemious living proprietors. Modern taxation had completely altered the supply of capital, and it must now be attracted from the rivulets of the many; only large semi-public corporations could command this capital. We might not like this difference of outlook or control, but it was inevitable, and therefore we must make friends with it

Alluding to the industries which were in difficulties at the present time, the speaker said first there came those in which the total output capacity was an uneconomic conception, because it could only be marketed if prices were so low as not to return net costs for that output.

This could arise even where there was no great difference of efficiency between the different units. Merging or combination would be a true rationalisation if it saved selling and advertised costs, and if it concentrated like production in particular units instead of splitting it amongst many. Arrangement for quotas and price-fixing did not force lower costs, and therefore preserved the relative *status quo* of the people in the industry, but made no contribution to the national problem or the export industries. It suited industries made up of jealous or rather selfish proprietors with no great difference in average capacity or enterprise. By common action they might not disturb the relations between themselves, but they might get the same aggregate profit, at a lower rate, from a large and cheaper production.

In the second class, total output capacity was a most unreal conception, because with wide differences in efficiency, a section of that total must be made by some units which had costs much lighter than the others, and could only be kept in existence at prices which would lose the whole trade. No merging or device which maintained these units in production could possibly be real rationalisation. The passion for quotas and output restriction in such industries was a national menace.

Highly capitalised units in the steel industry could only produce real benefits in low costs if they were pretty fully occupied—the drag of the quota going to the less efficient prevented this, and as a result a first-class plant half occupied might have very high costs.

A third class were the industries which were sharing a reduced world demand at common world prices, and were not relatively different from other countries in efficiency or costs Here, as possibly in the artificial silk industry, temporary limitation and price-fixing might well be superior to general rationalisation. But too many imagined themselves in this class who were really only hiding from themselves the truth about a general loss of world position through high costs, or a high percentage of obsolete units which were a drag on efficiently and cheaply-produced total output.

The chief causes of "stickiness" about rationalisation were—

(1) A disinclination on the part of highly individualistic producers to believe that their conditions were permanently bad. So long as they thought themselves in the trough of a trade cycle that would automatically come better they had no compelling incentive to unite or take drastic action.

(2) The lack of a catalyst or agent that would precipitate action, particularly if the financial supports behind the different units were rival banking interests.

(3) A desire to preserve the ancient status in any financial merger, regardless of potential future differences through technical equipment. Any merger was so capitalised to be unable to break up the *status quo*, and close the least efficient units, was doomed to failure. But if it were so heavily capitalised that it attempted to save potential losers from any actual loss, it was also hopeless.

(4) Secrecy and conservatism which kept anyone from knowing the total position of an industry or the relation of its parts. Mergers arranged on a purely financial basis, without some preliminary technical examination to guide the relative financial interests, were unlikely to be successful. A study of the German accomplishment was full of meaning as to the imperative need for early action in several parallel industries in this country.

"My opinion about Germany is that a very large part of her remarkably rapid recovery is due to the extraordinary energy she has put into rationalisation—by which I mean not merely cartels or groups, but actual scrapping of factories and renewal of plant. She has had to do this very extensively on borrowed money, and for a time she is going to suffer before she can get the benefits from a financial point of view. For example, in the coal and iron and steel industry the remaining units are carrying the capital cost of closing the inefficient ones,

and they are finding it very burdensome; but there is no question about the increased output at low costs which the existing units are able to give.

Another drawback of the rapidity of the German rationalisation is that the inevitable contribution to unemployment which is involved has proceeded a good deal faster than absorption. It is complained, too, by the industrialists that the rapid rise in wages and the heavy capital charges are depriving them for some time of any benefit. Rationalisation has hardly touched agriculture, despite the fact that the characteristic element of the German system has been not merely intense application to particular industries, but a nation-wide organisation of a most complete description for securing national efficiency in manufacture and distribution.

Germany has been modelling her methods on the United States, but there are two important differences. She has not such a wide market, and her labour is so much cheaper that she cannot profitably carry the process of mechanisation so far as they can in the United States. Where it would pay to replace labour by machines in the States, it does not in Germany.

The day has gone by when we can afford to ignore the important advantages obtained by large systematised German units compared with our own. Tranquillity is a fine thing, but it lies very near to danger.

I think that the activities of the Lancashire Cotton Corporation promise more favourable results than one might dare to hope for, seeing that they have only been in existence nine months. They are already in sight of 10 million spindles, and have under way centralised buying and selling, centralised services, and the avoidance of cross-traffics. They at any rate are not confusing mere financial grouping with rationalisation, because the technical aspect is prominent. That is clear from the number of cases they have rejected as being so backward as to make it impossible to bring them up-to-date with any reasonable expense. Is it not probable that the woollen industry will have to go through a similar stage?"

A vote of thanks to Sir Josiah Stamp was carried on the motion of Sir Donald Horsfall, Bart, seconded by Mr. Wilfred Turner.

London Section

Informal discussion meeting at the Institute Rooms, 104 Newgate Street, London, E.C., 4th December 1929, Mr. L. J. Mills in the chair.

LEATHER AND SKINS FOR CLOTHING PURPOSES

The Chairman said they were particularly fortunate in having Mr. Lamb, Principal of the Leathersellers' Technical College, to address them, and he was sure they would have a most interesting lecture.

Mr. Lamb said that he wished his audience to consider leather and skins from a clothing point of view. There was an old saying that there was nothing like leather. He would try and convince everyone that that was so. Everyone knew leather was the outer covering of an animal in a form which had been made soft and supple, and subsequently manufactured into articles of clothing and footwear. Leather was made up of innumerable fibres, and for that reason there were no mechanical means for reproducing it or for producing a substitute for leather. One found in leather, especially when used for clothing, that it contained properties which ensured perfect ventilation, and, unlike other materials of a non-porous character, it allowed the waste products of the human body, that was perspiration, to pass through or to be absorbed by the leather without condensation. It could also be made wind resisting and to some extent waterproof. It was further light weighing, soft, and durable. In its hygienic properties it was far in advance of any of its substitutes. The fibres in the leather had to be very carefully preserved during the tanning processes, and it must

necessarily have a good tensile strength. The raw material for a leather coat was usually sheepskin, and the first operation these skins were subjected to was soaking in water. After the skins had been left for a few hours the wool could be quite easily removed. Then followed the process of dissecting the fibres in order to ensure softness and pliability. That was carried out either by liming, or could be done by the paddle method. As soon as the article was clean it was necessary to get rid of the lime in its entirety before the tanning operations were commenced. That process was termed "bating," which meant that the skins were first washed with water and were then subjected to enzyonic treatment. Then followed the tanning operations, and if done by vegetable means, the skins were either suspended or laid flat and were moved from one bath to another, which gradually increased in strength. There were four or five different ways of tanning. It could be done by the ordinary vegetable method, it could be carried out successfully with alum or with chrome, or it could be done with oil. The vegetable tanning was a process employed for tanning sole leather, alum was employed in quite large quantities for gloves, but chrome was used for clothing leather of the better qualities and for a variety of different types of leather, such as glacé kid and calf leathers.

Continuing, Mr. Lamb said that in all classes of leather clothing the average lady had no knowledge of the quality of the leather she was purchasing. But there was leather and leather. Unfortunately, the lady would only set up one standard so far as leather was concerned; provided it was leather, that was all she cared about. There was good leather and bad leather, and he was sorry to say a good deal of bad leather was now being used in the leather clothing business. One of the most difficult operations in the preparation of leather for clothing was the dyeing and colouring, the more so because to-day manufacturers had to comply with many drastic requirements.

Considerable progress has been made in recent years in the manufacture of fancy leather, in the direction of considerably improving the finished appearance by the selection of dyestuffs fast to light and rubbing, and the obtaining of a more uniform and regular colour throughout the surfaces of the leather by the application of the so-called "pigment finishes." These finishes contained finely ground mineral pigments held in a state of suspension in a solution containing a binding agent such as shellac, casein, or gum arabic. These finishes were more generally applied by spraying at high pressure on to the surface of the dyed leather. This method of finishing overcame the difficulties incidental to the obtaining of a regular and uniform dyed surface upon a material which had been subjected during its lifetime, as was the case with the skin of an animal, to many accidents and defects.

A hearty vote of thanks to the lecturer was proposed by Mr. E. B. Fry, and carried with acclamation, Mr. Lamb briefly responding.

Lecture at Barrett Street Trade School, London W., on 18th November 1929; Mr. E. B. Fry in the chair.

VAT DYES, OR WHAT SHOULD THE PURCHASING PUBLIC UNDERSTAND BY FAST DYE

Referring to the fact that the public lectures arranged by the London Section of the Institute were, by the kindness of the Company, usually held in the Clothworkers' Hall, the Chairman said that it was an experiment, and, he thought, a successful experiment to hold this lecture in the West End. A further lecture would also be delivered in this end of London and he felt sure the Section Committee would regard the venture as justified and to be proceeded with next session. After a brief reference to the history of the Institute and its objects Mr. Fry introduced the lecturer, Mr. J. Blair.

The lecturer said he hoped to make clear what classes of dyes could be said to measure up to the public's present idea of fastness. It was important to realise that the public was being gradually educated to more stringent demands for fastness. Vat dyes very largely satisfied these demands but they could not be applied to all materials nor was it so easy to match shades with these dyes as it was with other classes of dyes only slightly inferior in fastness.

The lecturer described what were now known as vat dyes and the means of dyeing them based upon the use of the soluble leuco compound. These were reduction products and on oxidation the original insoluble coloured forms were secured on the fabrics under treatment. This to some extent explained the fastness of vat dyes. A brief historical outline of the dye-making industry was then given, and reference made to the work of Wohler, Perkin, Meldola, A. G. Green, Clavel, and others in this country and on the Continent.

The lecturer made special reference to the efforts to produce indigo synthetically and described the process now employed in its manufacture by the Society of Chemical Industry at Basle. The relative fastness of indigo on wool and cotton was discussed and its quality of fading pure emphasised.

Mr. Blair then proceeded to describe the progress made in the manufacture and use of anthraquinone vat dyestuffs—ranges made by various manufacturers being indicated. These dyes presented the highest fastness known among coal-tar dyestuffs. A brief résumé of the history of Sundour fabrics and their development followed, in which reference was made to the full story given by Mr. James Morton to the Royal Society of Arts in April 1929 Some reference was next made to the Hydron colours and to the relative cost of using vat dyes in place of other classes of dyes. Except in good depths of shade the extra cost per yard of fabrics dyed did not amount to much.

Finally, the lecturer came to the consideration of what should be understood by the public as fast dyes. The term was not the same to the purchaser of a casement cloth as to the purchaser of knitting wool. Tests for fastness to light, washing, water, alkali, acid, perspiration, rubbing, storing, chlorine, and ironing were applicable and different dyes gave different results which should interest and inform the public. Three factors determined fastness—(1) shade; (2) purpose; and (3) kind of material. These points were elaborated by the lecturer, who described fastness tests employed by the Clayton Aniline Company, and the work of the Committee appointed by the Society of Dyers and Colourists to inquire into the possibility of defining degrees of fastness of dyed materials. A description of the Neolan colours, a speciality of the Society of Chemical Industry, Basle, was given and particulars of their use for wool, silk, and leather. The lecturer illustrated his discourse with tests, charts, and specimens

A good discussion ensured in which many questions were asked from the point of view of the user as well as from that of the retailer or wholesaler. A hearty vote of thanks was accorded to the lecturer.

Scottish Section

Meeting at "Spread Eagle" Hotel, Jedburgh, on Wednesday, 22nd January 1930.

A party of about 22 members assembled at the hotel for lunch prior to visiting the works of Messrs. North British Artificial Silk Ltd., Jedburgh.

In the absence of Mr. Hartley, works manager, Mr. A. R. Knight extended a welcome to the Institute, and said that they were very pleased to have the opportunity of showing the members through the works that day. He hoped that the visit would prove of interest to all those present, and particularly those who handled rayon yarn in the course of their daily work. They would find no secrecy in the works, and were at liberty to ask any questions about particular processes viewed during their progress through the premises.

Mr. J. Macpherson Brown, Galashiels, on behalf of the Institute, expressed a word of thanks to the company for their kindness and courtesy in allowing the members to visit the works, and said that they appreciated very much the spirit which had prompted the directors to grant the necessary permission. Referring to Mr. Knight's remarks, he made an appeal for greater co-operation among the members of the Institute on general subjects, and said that they need not be afraid of giving away any information on matters of common interest, while there were many ways in which it was possible to work together for the benefit of the industry as a whole, and their own separate interests in particular.

Mr. J. H. Lester, Manchester, a Vice-President of the Institute, who accompanied the party, also spoke, and appealed to members to realise that there were great possibilities for closer co-operation on the lines Mr. Brown had suggested, and that the activities of the Institute provided an excellent medium for co-ordination towards that end.

Thereafter the members spent a very interesting and instructive afternoon visiting the works, conducted by Mr. Knight, who gave a detailed explanation of the various manufacturing processes employed in the production of rayon yarn.

Irish Section

Meeting at Belfast Municipal College of Technology, Thursday, 23rd January 1930.

The second meeting of the session was held in the Municipal College of Technology, Belfast, on Thursday, 23rd January 1930, when a lecture was delivered by Mr. W. F. Whiteford (London), on "Costs and Statistics for the Linen Trade."

Mr. W. H Webb, who presided over a very large attendance, appealed for a larger membership of the Irish Section of the Institute, and said every firm ought to have at least one of its members subscribing. Mr. Webb said that in the linen trade they had got behind in administration, and that Germany and U.S.A. were far ahead of them in that respect, though not in technique. He thought the report of the linen delegation to America was wonderful, and he hoped and believed it would mark a turning point in the trade.

Mr. Whiteford delivered an interesting lecture, and spoke of the need for standard costs and up-to-date statistics for the trade.

On the proposition of Mr. Garrett Campbell, seconded by Mr. F. Anderson, a hearty vote of thanks was passed to Mr. Whiteford and Mr. Webb.

NOTES AND NOTICES

The Late Sir Frank Warner

The passing of Sir Frank Warner, K.B.E., of Woodcroft, Mottingham, Kent, on Thursday, 23rd January, evoked wide-spread sorrow among a large circle of friends and business associates in many parts of the country and abroad.

He was born in London on 13th September 1862, the son of the late Benjamin Warner, founder of the firm of Warner & Sons, silk manufacturers, with works at Braintree, Dartford, and London. Leaving school in 1878, he went to Lyons for a year's course of study under Professor Audibert in the art of silk manufacture. Prior to entering his father's silk manufacturing business in London in 1881, he served for two years in a firm of importers in the city of London, and as a junior salesman in the warehouse of a firm of silk manufacturers in Wood Street. Joining his father's firm after a qualifying period in the factory, he was placed in control of the designing, cloth construction, and colouring of the hand-loom fabrics produced. In 1891 he became a partner in the firm, and on his elder brother's retirement in 1914, he became sole partner.

His success in an exacting business was due to an artistic temperament, an inborn sense of colour values, a love of beauty in all its forms, and a highly developed technique, enabling him to produce fabrics which speedily acquired a world-wide reputation for excellence of production and beauty of design. His technical skill was shown in his invention of three-pile velvets (which he patented), of which an example is to be seen in the Victoria and Albert Museum. To this artistic and technical skill were added the qualities of organisation and business acumen. He was a born leader of men. His mental grasp, his wise judgment, his power of getting things done were shown not only in the development of his own large business, but in the wider field of public service to which he soon began to devote himself. Few men have had greater calls upon them, and none have responded more generously, not only in the wide field of the numerous Committees and Congresses of which he was a prominent member (usually the Chairman), but also in the more intimate relationships of business and social life. His knowledge and experience were always at the service of those who came to him for advice and help. It is impossible to give any idea of the wide range of his activities, but naturally the claims of his own trade appealed very strongly to him. He devoted many years of service to furthering its interests, serving from 1910 to 1917 as President of the Silk Association of Great Britain and Ireland. He was also the inspirer and Chairman of the British Silk Research Association (the first Research Association formed in the country); Chairman of the Advisory Committee of the Imperial Institute on Silk Production; the author of the standard work "The Silk Industry of the United Kingdom," and of many addresses and papers to Schools of Art and other similar organisations.

For many years he was in close contact with the Department of the Board of Trade in all matters relating to textiles, and in 1917 he was officially appointed as Advisor to the Board on textiles (other than cotton). His work for his country was recognised in 1918, when a knighthood was conferred upon him. He was also an officer of the Legion of Honour, granted to him during the Paris Exhibition of Modern Art in 1925. As a citizen he was a Freeman of the City of London; a Liveryman of the Worshipful Company of Weavers; and for a number of years a member of the City Corporation.

His connection with the Textile Institute began in September 1909, when the small band of enthusiasts who had gathered round Messrs. George Moores and J. H. Lester (the founders of the Institute) met to make the arrangements for its official inauguration. Mr. Warner (as he then was) was among those present, and his application for membership is dated 21st December 1909. The inauguration took place on the 22nd April 1910, and at the first meeting of the newly

formed Council which followed on the 6th May, Mr. Warner was elected Chairman, and Professor Barker, Vice-Chairman. This office he retained until 1918, when he succeeded Sir William Mather as President for two years 1918-19, 1919-20. The task of building up and guiding a new organisation during the first ten years of its existence is always difficult, but when this period includes four years of war, some idea of the difficulties which had to be overcome may be realised. The Institute owes much to Sir Frank Warner. His tact, resourcefulness, and driving force were only equalled by the close comradeship and mutual trust which he inspired in all those who were working with him.

It is not too much to say that the success of the Institute as we know it to-day is due largely to the foundations that were laid, and the work that was done during his chairmanship.

The last few years of his life were clouded with sickness and sorrow. His own health failed, and he had more than one serious breakdown, which compelled him to relinquish his public work and other outside interests. Then in March 1928, after a lingering illness, Lady Warner died, and the home life, which had meant so much to him, could never again be the same. In the September following, his only son, Mr. Cloudesley Warner, who had been his partner in business since 1922, died in Normandy. Such cumulative sorrow was too much for his enfeebled frame, and although he retained his courage and sweetness of spirit, the zest of life was gone. He was still able to take some interest in his business, but after attending a Board Meeting he took a chill which developed into pneumonia. The finest medical skill was unable to arrest the progress of the disease, and in the early morning of the 23rd of January the web of life was completed, and the loom of life stopped. His body rests at Chislehurst, but his spirit, the spirit of a very gallant gentleman, is enshrined in the hearts of his friends.

The Late Mr. William Eastwood

A member of the Institute for many years, and an ardent supporter of the organisation at a time when his activities in textile works management were outside his own country, thus depriving him of really intimate contact with Institute affairs, Mr. William Eastwood, whose death took place early in January, was an individual of outstanding ability on the technical side of the industry. In pre-war days he was engaged in directing large-scale industrial organisations in Russia, and in those years he was a helpful member of the Institute as a correspondent, able and willing to give reliable information on many matters, including language translations. Like many others, he suffered considerably during the revolution in Russia, but nevertheless was ultimately able to return to his own country. During recent years he was a frequent visitor to the Institute headquarters, and the announcement of his demise came as a great shock to many of his fellow members. Mr. Eastwood had experience of many European countries, and he was an accomplished linguist. His death took place in Italy whilst on a visit to Milan. He was widely known in textile circles on the Continent, and had been responsible for several introductions therefrom to Institute membership.

Institute Annual Meeting

The next Annual General Meeting of Members of this Institute has been fixed to take place at Bolton, on Wednesday, 7th May. A programme will be issued in due course, giving particulars of the proceedings. The President of the Institute, Lieut.-Col. B. Palin Dobson, of Bolton, has kindly accepted nomination by the Council for re-election for a further year. Members are asked to note the date and place of the annual meeting at which a really good attendance is hoped for. An important item in the proceedings will be the contribution of the

Annual Mather Lecture of the Institute. The Council has already invited Mr. H. G. Hughes, B.Com., the Director of the Cotton Trade Statistical Bureau, to give this lecture, and the invitation has been accepted. The title of the contribution will be announced later.

Textile Institute Diplomas

Election to Associateships of the Institute have been completed as follows since the appearance of the previous list (November issue of this *Journal*) —

ASPDEN, John (Clitheroe)
BARROW, Christopher (Manchester).
CRAWSHAW, Harry (Burnley).
ETHERINGTON, Burton (Rochdale).
PILKINGTON, John (Oldham).
STUART, William Litherland (Halifax).
SUTTON, George Donald (Bolton).
WHITWORTH, John Richard (Royton, nr. Oldham).

Elections to Institute Membership

Whilst the monthly additions to our membership roll continue to be recorded in most satisfactory numbers, yet the Propaganda Committee, which gives constant attention to this vital matter of advancement of membership strength, asks for the assistance of members generally in this connection. Progress is discounted, however, by withdrawals which arise from various causes, hence the need for persistent effort The Secretary would always be pleased to approach individuals on receipt of names and addresses, and would supply application forms and suitable literature on request.

The following is a list of new members elected at the February meeting of Council—F Asquith, 3 Green Top, Pudsey, nr. Leeds (Designer and Inside Manager); B K Bose, 235 Windsor Road, Oldham (Spinner), M M. Charap, c/o S.A. Fabrica Argentina de Alpargatas, Buenos Aires, S. America (Chemist); Miss Irene Clark, 3 Charles Street, Nelson, Lancs. (Student), G Davis, "Amberlea," Huthwaite Road, Sutton-in-Ashfield, Notts. (Hosiery Manufacture, Clerk), G. V. Doraiswamy, c/o 4 Hollywood Road, Smithills, Bolton (Textile Student); B. B. Dutton, Westgarth, 56 Albert Road West, Bolton (Cotton Spinning, Apprentice), B Dyson, 36 Newsome Road, Huddersfield (Textile Teacher), W. Ellison, Lawside Dyeworks, Dundee (Director and Secretary). E. Gminder, Gustav Wernerstrasse 26, Reutlingen, Germany (Textile Manufacturer); F. C. Hewitt, 76 East Main Street, Webster, Mass., U.S.A. (Supt., Cotton Finishing Plant), N. Hodgkinson, Wesley Villa, Rawtenstall, Rossendale (Student); H. Jolly, Peel Mills, Turton Street, Bolton (Cotton Spinning, Director), Robert M. Jones, Saco-Lowell Shops, Newton Upper Falls, Mass., U.S.A. (Research Engineer); J. A. Kirby, 33 Stephens Road, Withington, Manchester (Textile Student), L S. Little, P O. Box 102, Slatersville, R I., U.S.A. (Vice-President and General Manager); J. H. Mackie, Wm. Hollins & Co. Ltd., Pleasley Works, Mansfield, Notts. (Mill Manager); Horatio B. Marchant, Textile Department, Technical College, Bradford (Student); John Ryan, Lancashire Cotton Corporation Ltd , Blackfriars House, Parsonage, Manchester (Executive Director); F. Watkinson, Crag House, Summerseat, Bury (Cloth Salesman); N. H. Williamson, "Alcuin," Bankhall Lane, Hale, Cheshire (Asst. Manager, Artificial Silk Manufacture). J. McKay Adan, 261 Clifton Road, Aberdeen, was elected to Life Membership of the Institute.

Council Meeting

At the last meeting of the Council of the Institute—Wednesday, 19th February—there was an excellent attendance, and a fairly lengthy agenda was submitted. Mr. Henry Binns (Vice-Chairman) presided. A draft copy of the annual balance sheet and accounts to end December 1929 was presented from the Finance Committee, and approved, and satisfaction was expressed owing to the improved state of the finances as shown by the revenue account. In this connection, it was reported that owing to a recent decision of the Inland Revenue authorities, it had been decided to accept agreement whereby income-tax will be payable on profits, but as a result it is expected that, after completion, members of the Institute will be able to claim allowance in respect of membership subscriptions. It was also reported that arrangements were proceeding for the holding of the annual general meeting at Bolton on Wednesday, 7th May. In recognition of their services, the Institute Medal is to be awarded to Col. F. R. McConnel, Messrs. J. Crompton, W. Frost, and T. Fletcher Robinson, and the presentations will be made at the annual meeting. The celebration of the coming-of-age of the Institute in 1931 has already received consideration by the Propaganda Committee, and a list of recommendations has been prepared. The various Section Committees are to be asked to offer suggestions as to co-operation in the celebration proceedings, which will probably cover two days, at Manchester, in April of next year.

REVIEWS

Year Book of the National Association of Cotton Manufacturers. Published by the Association at Boston, Mass., U.S.A.

The 1929 Year Book brings the total to twelve of this well-known and interesting series. The book as usual has been divided into two sections—Statistical and Technical—and in each former tables have been carefully revised and new material added. Of the latter it is suggested that study should be made of the domestic consumption of cotton by grade and staple for the year ending 31st July 1928, and the grade and staple report for the 1928-1929 cotton crop. For the first time the cotton manufacturer has a detailed picture of the particular parts of the crop in which he is interested. The data from the Census of 1927 are more descriptive of the industry, as they include more divisions by classes of fabrics and also divide the production of cloth into groups of fabrics with yarn numbers averaging 40's and below and above 40's. The Association is again to be commended on the comprehensiveness and careful compilation of its statistics. T.

The Chemical Age Year Book, Diary, and Directory 1930. Published by Benn Bros., London. (Price 10s. 6d. nett.)

The new edition of this Directory follows the style and make-up of previous years. In this respect perhaps a little criticism would not be out of place. The first 60 pages are devoted exclusively to advertisements, and while this is doubtless advantageous from an advertiser's point of view, it would be equally advantageous to the general purchaser and reader if the title and contents pages were given precedence. As it is time is lost in searching for these pages; alternatively the present form could be retained and tinted paper used to indicate the commencement of information. T.

The Meaning of Rationalisation. By L. Urwick, O.B.E., M.C., M.A. Published by Nisbet & Co. Ltd., London, 1929 (156 pp. and Index. 7/6 net).

On earlier pages of this issue will be found a report of an address by Sir Josiah Stamp on "The Latest Aspects of Rationalisation." The attendance at this meeting was very complete testimony to interest—vital and imperative—in this subject. Discussion in this, as in any other instance, must be based securely on an accepted definition of the term and all that it connotes or excludes. Sir Josiah emphasised this when he said "If it is true that rationalisation means nothing but mass production, monopolisation, and trustification, and all that these

things have meant in the past, then, indeed, the outlook is serious. It may be self-protective but it is nationally destructive." The book under notice is the considered production of a member of a voluntary Committee appointed by a meeting of some 50 institutions called to consider the possibilities of co-operation in inaugurating a national movement for rationalisation. It is avowedly published on the authority of the author himself but it is not unreasonable to suppose that he may be assumed to speak with the full sympathy of the other members of the Committee. In an attempt to secure a full understanding of what rationalisation should mean and does mean to those intimately concerned with its propagation it is natural, then, to turn to this monograph. The Industrial Committee of the World Economic Conference, 1927, produced a series of resolutions (Appendix A of this book) under the title of "Rationalisation" which were finally adopted by the Conference as a whole. These resolutions recommended "that Governments, public institutions, professional and industrial organisations, and the general public should influence producers to direct their efforts along the channels described—and diffuse in every quarter a clear understanding of the advantages and obligations involved by rationalisation and scientific management and of the possibilities of their gradual application," and it cannot be logically deduced from this, surely, that rationalisation appeared to the members of the World Economic Conference as "nationally destructive." It will be seen, of course, that Sir Josiah Stamp did not agree with the premise that rationalisation meant nothing but "mass production, monopolisation and trustification, etc." and in conjunction with his lecture this book may very usefully be read. Mr. Urwick deals first with the history and definition of the word and after doing so says that in this book the word may be defined as an attitude or as a process." As an attitude it records *the belief that a more rational control of world economic life through the application of scientific method is possible and desirable.* As a process it implies *the application of the methods of science to all problems arising in the organisation and conduct of production, distribution, and consumption.* Postulating that this is a much wider field than hitherto associated with the word, the author proceeds, in Chapter II, to consider the possibilities and extent of that field; in Chapter III, he defines and discusses the scope of rationalisation; and in Chapter IV he emphasises its importance to the business man. Chapters V—VIII cover scientific management, research, the field of management, and the field of administration. Finally, Mr. Urwick discusses the present position in Great Britain (Chapter IX); gives some suggestions for action (Chapter X); and draws conclusions in Chapter XI from which it is difficult to escape. The book may be heartily commended to all since it is by the "common effort of all classes of the community" that lasting improvements can be made and benefits secured. H.L.R.

La Grande Œuvre de la Chimie. Essays by various authors edited by Jean Gerard. Published by "Chimie et Industrie," Paris, 1929.

This is a collection of essays each dealing with differing aspects of chemistry in its relationships with human affairs. Not only industrial, hygienic, and physiological aspects of the subject are dealt with, but aspects of a philosophical character as for example, "La Chimie et l'évolution de l'humanité" and "La Chimie et la société moderne." The volume is issued as part of the scheme inaugurated by the French Society of Chemical Industry to commemorate the life and work of Marcelin Berthelot. The book contains a mass of information and serves admirably as a picture of the enormous part played by chemistry and chemists in almost every aspect of human activities. The illustrations are crude and not in keeping with the work as a whole. T.

Elektrobetrieb in der Textilindustrie. By Dr. Ing. Wilhelm Stiel. Published by S. Hirzel, Leipzig, 1930 (price, RM. 33).

The title chosen by the author, which may be translated as "Electricity in the Service of the Textile Industry," is indeed a very happy one, as his book covers not only the subject of driving textile machines by electric motors, but shows very clearly how electricity can be utilised in many other ways, to equal advantage, in the textile factory.

This book is the first in the world's literature which systematically shows how electricity may be applied for driving and other useful purposes in the textile industry, no matter which branch of the industry may be chosen—it shows also

how much further ahead the study of electro-technics in regard to textiles is on the Continent than in either England or America. As an instance, the special drives mentioned for ring spinning frames, flyer frames, jute flyer frames with individually driven spindles, individual mule drives, electric spindles for ring frames, printing machine drives, etc., might be cited.

Not only is this book of immeasurable use to the electrical engineer, but should be in the hands of all engaged in the textile trades, progressive textile machinery makers, and textile students, especially at such a time as this when rationalisation of the means of production is so much to the fore. As a book of reference, whenever the question of the use of electricity is raised, it must prove to be of invaluable assistance.

The book, which comprises some 650 pages with about the same number of diagrams and six double-page drawings showing the diagrammatic lay-out of textile machinery, is divided into three main parts. The first part after the introduction, which gives a short history of the textile industry, including several extremely useful tables of the world's spindles, looms, etc., deals with the general question of source of power, whether steam, electricity, or oil, going very closely into the problems of mill heating and the utilisation of heat for process work. There are a number of excellent diagrams and curves illustrating the author's remarks. This first part concludes with very clear examples of methods for dividing up, controlling, and generally distributing electric circuits to their best advantage for the particular duty they are designed to perform, with chapters on transformers, converters, and the layout of typical generating stations. The second part deals exclusively with the interesting subject of electric motor drives in textile works, which drives, the author divides into four main groups, showing the many advantages of not only what is generally known as individual electric drive, that is, one or perhaps two motors to a machine, but goes further to point out that even better results may be obtained by individually driving the various parts of one machine, by means of a larger number of small electric motors, such as are now becoming general in the drive of artificial silk spinning frames, jute spinning frames, etc., where each spindle is driven individually.

The data given by the author in the various power consumption curves must prove of great interest and usefulness, especial mention perhaps should be made of those consumption curves relating to ring spinning frames. The second part covers not only the application of the electric motor to various textile machines, but draws special attention to the type of motor which should be used in each case from the bale opener in the cotton mill to all the preparation machines and finishing machines in the flax, hemp, jute, worsted, wool, real silk, artificial silk, artificial wool, and rope industries. For all the separate machines used in these industries the fundamental principles for the arrangement of the individual electric motors are shown and the accompanying sketches and lay-outs leave nothing to be desired.

Before leaving this second part attention is drawn to the chapters on electrical driving of knitting frames, sewing machines, and lace machines and last, but by no means least, those devoted to the numerous drives in bleach works, dye works, and print works. Drives for printing machines have always been an interesting subject from the electrical engineer's point of view, and are now very clearly described with the various possibilities by the author

If any distinction can be made, perhaps this second part is the most valuable as it contains really excellent constructive information, leaving little or nothing to the imagination.

The third main part treats with those essentials to the efficiency and comfort in any textile works, essentials which are only too often completely lost sight of —these are lighting and heating, etc. Here again tables are given clearly showing the amount of artificial light required to illuminate effectively the various departments in relation to the floor area of those departments, taking into account the decoration, shape, and machinery installed. A special chapter is given on electric heating, arrangements being shown for the heating of the different departments, both by water, steam, and hot air. Other subjects dealt with in this part of the book are the electric air purification plant, static electricity, and its effect on cards, drawing frames, spinning frames, etc., and the electro-magnet and its uses, whilst further chapters deal with measuring instruments for power

and temperature control, special diagrams and arrangements are shown for remote control of humidity, etc. The subject of electrically operated warp and weft stop motions is clearly explained.

No book of this nature would be complete without some mention of the uses of electricity in chemistry and the author deals at some length with the subject of electrolysis and copper recovery plants. The last chapters show how electricity may assist transport in the mill, not only by using electrically-driven overhead travellers, but also by the adoption of electric trucks—these should be of especial interest in the scattered mill. The mechanic's shop, a most useful, but often overlooked portion of any textile works, has not been forgotten. A complete index of articles on the subject of electric drives previously published is added, together with an alphabetical index of the contents.

Taken all round this book is the most comprehensive one of its kind ever published and Dr. Stiel, who for many years has been head of the Textile Department of Messrs. Siemens-Schuckert, Berlin, is to be congratulated and thanked for the clear way in which he has dealt with a subject at once so immense and of such vital importance. Although as yet this book is only published in German an early translation into English is hoped for. R.H.F.

The Finishing of Woven Fabrics. By Eber Midgley, F.T.I. Edward Arnold and Co., London (207 pp. and Index; 18/- net).

The primary object of this book is stated by the author as an attempt to demonstrate the underlying principles of the chief factors in cloth finishing, and as will be seen from the following brief review the attempt has met with considerable success in view of the wide field which the author has to cover in a volume of some 200 pages.

Part I—General—deals briefly with the constituents of woven fabrics and their effect on appearance and handle in finishing, and also on the influence of materials, yarn, and cloth structure on the finished fabric.

Part II includes chapters on Crabbing, Scouring, and Milling and Finishing of all wool materials. With reference to the first of these processes there are a few excellent illustrations for comparison between crabbed and uncrabbed fabrics. The processes of scouring, milling, and raising are only briefly dealt with, although useful diagrams of the essential machines are given. Descriptions of the processes and machines for drying and tentering, steaming and brushing, cropping, pressing and permanent finishing are also included in this section.

Part III deals with the Finishing routine for Union Fabrics, composed of cotton warp, worsted, mohair or alpaca weft. The processes are—crabbing, scouring, drying, and singeing. These processes are interesting by comparison with the treatment given to all-wool goods. Particulars are also given of the variation in dimensions of a few standard cloths after the various finishing operations.

Part IV deals with the Mercerising and Schreinering of Cotton Goods. Mercerisation is made use of in the finishing of cotton goods to develop a lustre much superior to that obtainable on more expensive makes of cloth such as the lustrous fabric obtainable from cotton warp and fine botany worsted weft. The author also gives tables of particulars showing the variation in cotton yarns before and after mercerising. Schreinering is dealt with at considerable length, and the general principles underlying the production of a silky lustre on cotton goods by this process are elucidated.

Part V concludes the work and deals with the influence of the Dyeing and Finishing Processes on woven fabrics.

The author has been successful in embodying an outline of practically all the essential processes in a comparatively small volume. Each section could have been greatly extended by consideration of various details in cloth finishing and their effect on the routine of finishing. The author, however, makes no pretence at an exhaustive treatise, but as indicated above, an attempt to demonstrate the underlying principles involved in cloth finishing In this he has been most successful and the book is a useful contribution to general textile technology and should be of the greatest value to those desirous of obtaining a general knowledge of the finishing of the various types of woven fabrics. D.R.C.

Wool Year Book. Compiled and published by the *Textile Mercury*, Manchester, 1930 (xciii + 696; price 7/6).

Reviewing the year 1929 in the twenty-second edition of the Wool Year Book, regret is expressed that the high hopes with which the Yorkshire textile trade entered upon the year were not justified. The revised sections of the volume prove that the year was not devoid of encouraging features, having particular regard to the collaboration now taking place between investigators in this and other countries with a view to the general betterment of trade. As usual all processes are dealt with from raw material to the finished goods, including artificial silk in addition to wool. List of technical schools, textile societies, trade associations, and a glossary of textile terms complete this handy work of reference. T.

Principles of Woollen Spinning. By Howard Priestman. Published by Longmans, Green & Co., London (334 pages and Index. 15/- net).

A first edition of the book was published in 1908 and this notice relates to the second edition now available, dated January 1924.

In general, the book preserves the same character as the first edition, although alterations have been made; the only really new feature is an extra chapter on "Woollen Frame Spinning," comprising approximately 20 pages

The work is somewhat disappointing; one expects more up-to-date information and perfected detail in a new edition of a technical book. On page 84 a table is given showing "Persons employed in various Countries in the Woollen, Worsted, and Shoddy Industries, including Dyeing," where the information is not later than 1902, again, the table giving "Return of Persons employed in Factories" concerns the year 1901, further, table 9 shows "Spindles running in 1904; table 10 relates to value "in dollars" of "Materials used" in the years 1860 to 1907, table 11, "Statistics of Shoddy made and used in the United States" refers to 1900, whilst table 12, "Method of Costing a Carbonised Carded Dyed Black Merino," would have been much more useful if changed from a pre-war to a post-war basis.

In passing, a number of details are noted on which comment by the author might have been usefully made, or novel features discussed and reasons set out for the inclusion of variations from orthodox methods. On page 48, the author states "it is well known that soap is a necessity for milling, and as acid causes the very opposite effects to those produced by soap, there is good reason to postpone carbonising until the milling has been effected", though this fact may be well known, it would have been helpful to student readers, particularly those interested in certain trades where acid milling is general, to know more of this subject.

Dealing with the Fearnaught, a detail diagram is given on page 144 which is certainly unusual, and any machine made on these lines would have to be specially ordered, the stripper is shown on the feed side of the worker, whereas it is normally mounted on the side of the worker nearest delivery, further the teeth on the stripper instead of having a definite "set" as illustrated, are in practice almost straight.

Again, when discussing the Garnett machine on page 147, it is stated "Garnetting is a near approach to carding proper, although the only rollers that have flexible clothing are the fancies," a diagram is also given, Fig. 21, showing Garnett fancy with flexible type of clothing akin to the clothing on an ordinary carding fancy— surely the ordinary practice in Garnetting is to have the fancy covered with Garnett wire-- the author should have explained this departure from the normal

In a similar way, on page 191, a diagram of a portion of a carding machine is given, with the stripper mounted on the doffer side of the worker, it is suggested that in a book on "principles," in case of any change from the standard—as this undoubtedly is attention should be directed to the alteration and an explanation given.

Relating to the same diagram, when referring to the setting of the rollers, the author points out, "it must be possible to move every stripper nearer or further from the centre of the swift (line 4, Fig. 41), as well as along a line connecting their centre with that of the worker that they clear (line 5), yet on page 200 is given another diagram showing relationship of cylinder, worker, and stripper as

they are under normal conditions but showing the setting bracket of the stripper capable of adjustment *only* in relation to the cylinder, which is, of course, the usual arrangement

Turning to condensers, a rather novel form of double rubber condenser is indicated on page 251. This idea seems out of place in a work on "principles." Probably the author intended it as the basis for an application to be made to the Patent office, but owing to an oversight it has received prior publication. At any rate it is unusual and does not seem capable of giving good work on average materials under ordinary working conditions.

In chapter 10, "The Mule," is given a diagram, Fig. 93, "Spindle and Roller Gearing"; perhaps when a further revision of the book is required, this diagram will be modified by deleting the scheme for spindle driving, or a full and correct drawing substituted.

Regarding matter in section on "Woollen Frame Spinning"; statements are made which should be queried, as for instance, "there are quite a definite number of turns in the portion which lies between the deflector rods and the back rollers, and it is here that the greatest amount of drafting is done," the last sentence is open to serious doubt, for assuming "no fibre measures $1\frac{1}{2}$ inches in length" and "the twisting tube is nearly 6 inches long," the drafting must take place between the nip of the front rollers and bottom grip of the twist tube, or between front rollers and top edge of the twister tubes, or where the roving is deflected and the twist changes in direction, just in accordance with the number of turns of twisting tube per unit length delivered by back rollers.

The detailed comparison of production costs for spinning on mules and frames is formulated on the basis of wages for labour, cost of power, and rent for space occupied. Information as to influence of capital costs, running expenses, adaptability, costs for extreme changes, yarn and fabric characteristics due to the use of respective machines, would have been appreciated. Ho

THE JOURNAL OF THE TEXTILE INSTITUTE

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PROCEEDINGS

Lancashire Section

Joint Meeting of the Institute and the Committee of the Royal Technical College, Salford, at the College, on Wednesday, 15th January 1930; Alderman Joseph Willett presiding.

SALESMANSHIP

The Chairman said that in connection with the work being carried on at the College in training students in salesmanship, it was particularly gratifying to be able to record that the classes held were increasingly successful. He felt that they were particularly favoured on the occasion in having Colonel Dobson, President of the Textile Institute, to address them.

Colonel Dobson expressed his appreciation of the invitation extended to him to address the meeting, and assured his audience that the work done by the College had a very real interest for him. Continuing, he said, "At the present time, when so many industries in this country are passing through a period of depression, and manufacturers are examining every means of improving trade, the question of salesmanship is receiving that attention which it always warranted but which in the past it has been denied. Manufacturers always carefully considered their raw materials, methods of manufacture, costs of production, the quality and quantity of the goods produced, but salesmanship was allowed to look after itself. 'Make a good article and it will sell itself' was a familiar statement once heard in Lancashire, and though perhaps it is still to some extent true, with world-wide competition it is advertising and salesmanship which captures or retains markets. Advertising and salesmanship go hand in hand, either is robbed of its effectiveness alone; a combination of the two effects the greatest results.

Leaving the question of advertising, let us ask what exactly is meant by salesmanship ?

It means the art of directing the placing of manufactured goods, of any class or description, on the markets of the world, with a maximum efficiency. It has nothing to do with the commercial traveller. This may sound paradoxical, but nevertheless one may be a master of salesmanship yet a bad salesman, even as one may be fully qualified in horsemastership and yet a bad horseman.

The qualities of a salesman depend on many physical and mental attributes; personal appearance, education, tact, persuasiveness, and, above all, a knowledge of human nature. The commercial traveller, as the word is generally understood, usually has some simple commodity to sell, but the salesman of highly technical apparatus must have other and special qualifications. It is comparatively easy to sell, say, an automatic collar stud. Other relatively simple commodities, such as silk stockings, drugs, gloves, or toys, require that the traveller shall possess enough knowledge of the goods to enable him to expound the merits of his particular article to the possible purchaser. A certain 'patter' regarding the processes of manufacture and the efficiency of the article in question is desirable, and may help to complete a purchase; but it must be remembered

that neither the buyer nor the seller has a complete and practical knowledge of every stage in the process of manufacture. Both seller and buyer meet on common ground.

The salesman of mechanical goods—textile machinery, turbines, aeroplanes, electrical plant, mining and metallurgical equipment, launches, motors, locomotives, scientific instruments, and so on, requires other qualifications. He should possess a technical and comprehensive knowledge of the machine sold; he should be furnished with information regarding every advantage that the machine possesses over competitive makes, and he should be able to discuss with the solicited purchaser any technical point which may arise. In this case special training is necessary. It is absolutely essential that the salesman should be trained in the practical side of manufacture. In other words, he must go through the shop—this is essentially the difference between the salesman and the commercial traveller. For the latter to sell collar studs, patent medicines, or gloves, a knowledge of the process of manufacture, although always desirable, is unnecessary. In the case of machine sales the competent technical salesman must persuade an equally technical buyer of the superiority of the machine he wishes to sell, and must demonstrate its advantages, economies, and efficiency.

There are possible exceptions; a salesman might have to sell a motor launch to a greenhorn or an experienced yachtsman. If the salesman realises that the purchaser is a technical man he approaches him in the usual technical way, but if the purchaser is a greenhorn then psychology opens the way. If the would-be purchaser is a man who, whilst knowing nothing, considers himself an expert, he must be treated accordingly. To make a mistake in the type of 'would-be purchaser' may be to make an enemy for life, not only for yourself, but for the firm who employs you.

Again, there is very often one particular point either in mechanism or construction on which the would-be purchaser is immovable—his idea may be entirely misconceived, perhaps even mechanically or structually wrong. If the latter, extreme patience is necessary to wean him from his misconceived ideas. If there is mechanical or structural difficulty, he knows it and you know it, and it is folly to push the argument beyond a certain point. It is often considered the business of a salesman to make a buyer purchase something which he does not want, and for which he has no use. This chiefly applies to gadgets which are bought in thousands by people who do not want them. Gadget hunting is almost a mania with some people. They are, and rightly too, the prey of the expert traveller.

Salesmanship and salesmen meet on the question of what the customer desires. The salesman goes out with the product of the industrial establishment which he represents and does the best he can to obtain markets for it, but he—far more than any technical expert in the factory—knows what it lacks in the customer's eyes, and can report what the customer really requires. It has for too long been a habit of industrialists to underrate the importance of this part of a salesman's work. He is quite as important as the technician in this respect.

Again, the salesman is handicapped if he is not backed up by good salesmanship in the way of advertising. The name of the firm should always carry weight and be associated in the minds of buyers with its products. This can only be done by a close co-operation between salesmanship and salesman—that is, by good public advertisement. Next, as to the question of personal appearance, I mean dress, manners, deportment, and physical appearance. It is folly to say that these do not matter; they matter a great deal. Very often, more often than not, the first impression is the one which counts most. Even if the good impression is eventually modified, it leaves at least a good primary background, on which a new impression may be constructed. On the other hand, a bad impression is probably the last. In neither dress, manner, or deportment must the thing be overdone.

This brings us to education, and by this I mean board school, public school, or 'Varsity education. Technical education has already been mentioned. What value may be placed on public school education ? There is no doubt that it has a distinct value in salesmen, always provided that the other attributes are equal. It is certainly more essential in some businesses than in others, but I imagine that on the whole there is no possibility of dogmatising on this question."

Turning to the differences in salesmanship demanded by widely differing classes of goods, the speaker dealt with a few specific instances in illustration of his point. It was futile, he said, to try to sell calculating machines to a tobacconist, a parson, a policeman, or a poet. The salesman of such goods must seek buyers among company secretaries, and those whose business demanded the use of such machines. Cotton yarns presented an entirely different problem, and questions of price largely predominated. The cloth salesman had a wider orbit still, and probably required a more extensive technical knowledge. The salesman whose commodity was textile machinery, required a deep and wide technical training—a training two-fold in character. Not only should he know the machine thoroughly and how it was made, but he should know what it could do and what goods could be produced upon it. Though not able to tackle every mechanical or manufacturing problem presented to him, the salesman of complicated machinery should know enough to enable him to present the problem plainly and tangibly to his firm's technical staff.

"Where does this lead us in education for salesmanship ?" asked Col. Dobson. "Undoubtedly to one fact ! Education in sales for all classes of goods can only be given collectively in an elementary manner, after which prospective salesmen must specialise in the knowledge of manufacture of the particular goods they intend to sell. The more they specialise the greater their chance of becoming thoroughly efficient salesmen.

The salesman, as has already been stated, must have the backing of the most efficient advertisement, as he is to push his goods to the best advantage. The greatest help to the publicity department are the reports of the salesmen; they show those whom publicity has failed to reach. They know the article, be it machine or collar stud, which is at the moment most attractive to purchasers. They have their hand on the pulse of the market, and their advice to the publicity department should be quite as valuable as their advice to the technical department.

The art of advertising is far too big a question to be dealt with in a paper of this length, but it is the one thing that the English manufacturer is quite alive to. It is still almost in its infancy as far as years are concerned. Every civilised man or woman requires clothes, food, amusements, sport; but every man or woman does not require an electric rotary converter, a carding engine, or a micrometer. Therefore you advertise the personal needs of man *ad lib*, and you restrict the advertisement of specialities to such technical journals as devote themselves to these particular trades. Even in scientific or industrial journals the advertisements must be attractive. Advertisements may be grotesque; they may even be vulgar, but as long as they attract the necessary attention they may be considered efficient. The unforgivable sin is to perpetrate an advertisement which is merely mundane and unattractive.

Every big business now runs its own publicity department, and a very important part of salesmanship now rests in the hands of those broadcasters of the merits of the goods to be sold. The invention of slogans is important, and these are used more and more in journal advertisements in order to catch the reader's eye. Even the engineering and allied trades have adopted them." Colonel Dobson then gave instances of slogans used in textile advertising, commending or criticising in each case. He pointed out that even if not perfection, such display did attract attention. He continued—"It will be seen that our publicity departments to-day are adopting a type of advertisement which used

thirty to forty or more years ago, by the advertisers of public commodities, was responsible for huge sales and the accumulation of fortunes. Who does not remember 'Worth a guinea a box,' 'Won't wash clothes,' and others of that ilk? A man may be a master of the art of advertising, and yet unable to sell a penny stamp without sustaining a loss. The publicity man and the actual salesman should work hand in hand.

Popularity is a fickle jade; when once you have attracted her attention it is necessary to keep it, otherwise she will turn her eyes to something novel, and you will get the cold shoulder. Therefore it will not do to be satisfied with one great slogan or one great advertisement which has made a hit. Every effort must be made to excel it in the next.

Perhaps it will be wondered why no special reference has been made to foreign advertisement and foreign salesmen, particularly as our export trade is all important, and my reply is that what has been said of salesmanship generally equally applies at home or abroad. Of course, when dealing with foreigners in their own country a salesman, to be a success, must have a comprehensive and colloquial knowledge of that country's language, including all the technical and trade terms used; in addition he should be thoroughly conversant with the customs of the country, and be able to adapt himself to them.

Regarding the customs of the country, one of the principal things to be considered is the type of goods that the particular country desires. The salesman can be of considerable assistance to his firm in keeping them *au courant* with the particular class of goods which his overseas customers demand.

The essential qualifications of an efficient salesman are a practical apprenticeship and good technical education. These two things are the foundation stone on which efficient salesmanship is built as far as big productive industries are concerned. Things may be different as far as the qualifications of salesmen in stores; they probably are, and I am in no position to speak from that point of view. This lecture must only be considered from the industrial aspect."

A very hearty vote of thanks to the lecturer was accorded by a large and appreciative audience. Colonel Dobson again expressed his pleasure at being asked to speak, and his gratification at being made so welcome.

Yorkshire Section

Joint Meeting with the Halifax Textile Society at Halifax, Wednesday, 15th January 1930.

HUMIDIFICATION IN TEXTILE WORKS*

This address, illustrated by a very extensive and interesting series of lantern slides, was delivered by Mr. H. W. Martin, of Messrs. Matthews & Yates, Swinton. In the course of his remarks he pointed out that the condition of the atmosphere in any textile factory is of prime importance both to the health and comfort of the workers and in its effect on the work going on. All textiles are hygroscopic materials; they readily take up or give out moisture according to the hygroscopic condition of the atmosphere. They stretch in a humid, and contract in a dry atmosphere, and are very sensitive to changes in the percentage of humidity of the atmosphere. The outside atmospheric conditions vary considerably from day to day, and at different times in the same day great changes in the percentage of humidity may occur. In England we are favoured with perhaps the best all-round climatic conditions in the world. It is never very hot nor extremely cold; the humidity of the air is fairly constant compared with some other parts of the world, and there is always some air movement.

Three most important factors—temperature, humidity, and air movement determine the condition of the air. The value of maintaining the correct degree

*The full text of this lecture is to be found in the *J. Halifax Textile Society*, February 1930.

of humidity in the atmosphere of a textile works is now fully realised. When the air is too dry all textile materials become brittle and less workable; frictional electricity is generated, which causes the fibres to repel one another, and dust and fly in many processes become excessive. Not only must the air in the room be renewed to keep it reasonably pure, but air movement in the room is very beneficial. The cooling effect of air in motion is much greater than that of still air. If the air is in a state of movement a higher temperature and a greater percentage of humidity can be used without creating uncomfortable conditions. The comfort condition depends chiefly on the rate of cooling of the human body.

The Kata thermometer (invented by Professor Leonard Hill) measures the rate of cooling of a surface at approximately the human body temperature under variable atmospheric conditions, and is a more reliable instrument for measuring the comfort condition than an ordinary thermometer.

The Lecturer exhibited and described a slide of a standard humidity chart from which absolute humidity per cubic foot of air could be read, as well as relative humidity. Various types of humidifying plant and installations in different buildings, such as flax hackling shed, ring spinning room, weaving shed, and other non-textile factories were illustrated and described. Methods of automatic control of humidity conditions were detailed and slides exhibited.

The lecturer was heartily thanked for his interesting lecture after a vote of thanks moved by Mr. Robinson, and seconded by Mr. Lee had been carried unanimously.

London Section

Meeting at Barrett Street Trade Schools, London W.1, on 17th February 1930, Mr. F. Henley presiding.

MAN'S QUEST FOR FIBRES

The Chairman, introducing Mr. R. J. Steele, M.B.E., of the Bradford Dyers' Association, said he had done very distinguished work in regard to textiles during the war.

The Lecturer said the address might with equal truth have been entitled "Man's Quest for Colour," the reason being that these two quests had gone hand in hand for a very long time. At the time when Great Britain was in a primitive state, the mummy cloths which were on the table showed that spinning and weaving had in the East reached an advanced stage. Silk, which was used in China about 2000 B.C., and in the Near East in the sixth and seventh centuries, came to France in the 16th century, and to England in the reign of James I. Silk had a great industrial past, and was known in China for thousands of years, and he had read that the very word "China" was closely allied with the Chinese word for silk. He then referred to the 17th century, which was a time associated with what might be spoken of as the birth of modern chemistry—the time when knowledge was emerging from the darkness of the Middle Ages. The result of the birth of this new knowledge was the rise of industrial chemistry. Pasteur was a great link between science and industry, and he rendered valuable service by his discoveries in regard to bacilli or microbes, and he laid the foundation of modern surgical hygiene.

As textile people, they were interested in him for another reason. The culture of silk had for years been subject to pests and diseases; Pasteur studied these problems working at the Polytechnique, Paris, and thus he became familiar with the way in which the silkworm produced a continuous filament of remarkable strength. One of Pasteur's pupils afterwards became Count Chardonnet, and a story was told of an accident to a receptacle containing collodion which gave rise to the idea of squirting out a substance in a similar way to which the silkworm extrudes the filament.

The Lecturer then proceeded to describe the use and development of the rayon industry. He referred to the work of Cross and Bevan, and to the various types of rayon yarns now available. Reference was next made to the "staple fibre" industry, and it was pointed out that its use probably arose from the desire to use the older type of machinery in conjunction with the new fibres.

Mr. Steele next turned to the subject of colour and dyestuffs, which, he said, had been used for thousands of years. In earlier times berries, roots, leaves, earths, and insects had been used to make colouring matter. A description followed of the introduction and development of aniline dyes.

Here Mr. Steele showed a dress, which was made in 1857, of a shot mauve shade, which he had analysed and found was dyed, both warp and weft, with aniline colours. He then proceeded to carry out a number of dyeing experiments. By practical demonstrations he showed how certain dyes have an affinity for one fibre and not another. He showed the development of a dye upon the cotton fibre itself. He closed a most interesting series of experiments by demonstrating the difference in fastness in two samples of lining.

The Lecturer went on to say that if he, a dyer, concluded his lecture without reference to "fastness" he would be guilty of avoiding a subject which had been the cause of a good deal of controversy at various times. The word "fast" was a relative term, and there was no such thing as an absolutely fast dye. It had to be looked upon from so many different angles. There was fastness to light, fastness to washing, fastness to rubbing, fastness to storing, and fastness to bleaching. A colour might be very fast in one direction and not in another. In the main, colours to-day were a tremendous improvement on what they had been in the past, and within certain limits of shade there was no question that the dyer of to-day could give the fastness that was required.

The Chairman said he felt they would all go away with a great deal of regret in their minds that this fascinating lecture had not been longer. He was, however, sure he was expressing the feeling of all present that the experiment might be repeated next year, and they hoped to have the opportunity of hearing Mr. Steele again.

Mr. R. S. Meredith said he thought they would all agree that they had never had a more interesting lecture than that one. He associated himself with what had been said by the Chairman in expressing the hope that Mr. Steele would come and lecture to them again, and he proposed a very hearty vote of thanks.

Mr. E. B. Fry, seconding the vote, said they had had one of the most interesting lectures which had been given to the Textile Institute in London. The Lecture Committee would endeavour to enlist Mr. Steele's services again.

The vote of thanks was carried with acclamation, Mr. Steele briefly responding.

Scottish Section

Meeting at Galashiels, Wednesday, 12th February 1930.

By the courtesy of Messrs. Wm. Brown, Sons & Co. Ltd., a party of twelve members visited the firm's Wilderbank Mills in the afternoon, and were conducted throughout the various departments.

Most of the visitors were from Dunfermline district, and in many cases the processes inspected were vastly different from anything appertaining to the linen trade, so that the visit was particularly interesting from that viewpoint.

In the evening a meeting was held in the Scottish Woollen Technical College, Galashiels, at 7 o'clock, Mr. J. Macpherson Brown, F.T.I., in the chair, when there was an attendance of approximately thirty.

The Chairman introduced the speaker, Mr. A. R. Geary, A.T.I., Dunfermline, and expressed regret at the small attendance of members from the Border district. He welcomed the members from outlying districts to Galashiels, and thanked them for their support at that meeting. He also took the opportunity of thanking

those members from Dunfermline for the excellent and attractive display of linen fabrics which had been arranged in the hall for the benefit of those attending, and hoped that everyone present would have a chance of viewing them before the end of the meeting.

The Lecturer then submitted a paper on "Costing and Pricing in Linen Weaving," giving a general system of apportioning costs which might be adapted for other textile manufactures, with explanatory remarks on particular instances of his own experience, and his remarks were followed with keen attention by all those present.

The meeting was afterwards thrown open for discussion, and among those taking part were Messrs. Brown, Lees, and Dr. Oliver, Galashiels; A. W. Blair, Glasgow; and W. B. Robertson, Dunfermline.

The Chairman proposed a vote of thanks to the Lecturer, and Mr. W. B. Robertson expressed the Institute's appreciation of the privilege extended to the members that day in being permitted to visit Wilderbank Mills, and for the courtesy shown to them on that occasion by the respresentatives of Messrs. Wm. Brown, Sons & Co. Ltd.

Mr. A. W. Blair, Hon. Secretary, also spoke, and associated himself with Mr. Robertson's remarks, at the same time thanking Dr. Oliver for his assistance in arranging for the meeting to be held in the Scottish Woollen Technical College.

Irish Section

Meeting at the Municipal College of Technology, Belfast, Thursday, 13th March 1930; Mr. F. Anderson presided.

STYLE, FASHION, AND MODERNITY IN TEXTILE DESIGN

The third meeting of the session was held in the Municipal College of Technology, Belfast, on Thursday, 13th March 1930, when a paper was read by Mr. R. A. Dawson, of the School of Art, Manchester, on "Style, Fashion, and Modernity in Textile Design." Mr. F. Anderson presided, and there was a good attendance.

Mr. Dawson, after referring to the present difficult condition of trade and the necessity for revising all the uses of machinery and appliances, said he proposed to take up the question as to how modern possibilities could be utilised to produce fabrics which should not only be satisfactory in structure but should have an artistic appeal. He hoped he might induce an attitude of mind which might bear fruit.

Education had made a great difference in this country and all over the world, so that we could not expect the inferior goods of the Western European market to satisfy either Colonial or foreign demand. There was a tendency for the peoples of the world to approximate to the standards of Western Europe, and to require goods presented upon a higher artistic plane.

The lecturer believed that the machine had established a permanent position in human economy. We had not yet realised fully its proper function. There would come a time when we should produce the using things by machinery, but we should realise that there were certain personal things, treasured things, heirlooms, not made to wear out, that would be recognised as being made rightly by hand. In industrial design as in other branches of modern work, there were workers who merely carried out instructions with skill—in fact, designer-craftsmen. There should be another type developed—a creative designer of a new type. The creative designer would be a leader. He would be in touch with the directors of the firm and in constant consultation. He would work not under the ordinary conditions of labour, but would have the freedom of a leader with suitably inspiring quarters and freedom to get about to refresh his mind, to restore his imagination. He would have a suitable salary to repay him for his years of

study, because such a creative artist could not be produced in a day. Industry would have to agree to take such designers without apprenticeship at a later age, just as in some branches students are taken from a University after a degree course.

Referring to style, the lecturer said that historic styles were very broad, and depended upon great changes in human life bringing a change of outlook. Possibly we were on the threshold of a new broad style in which all human requirements were being revised in terms of machine production.

Fashion implied on the one hand change for the sake of change, but on the other hand, imitation. It implied a social psychology in which certain people were impelled to distinguish themselves from others in outward appearance, and having done so, the sheep instinct of the rest followed in more or less degree, until the distinction aimed at at the beginning was no longer apparent, and it was necessary again to create a distinction by another change; and so the process went on.

The study of styles was not recommended for purposes of copying, but as part of the mental background for the originality of the artist with a well-stored mind, with imagination, and with modern outlook. The training would necessarily cover technical knowledge, even more so with the designer-craftsman than with the creative artist, and colour study was all important at the present day, when there was coming about an awakened colour sense and a desire for brightness and liveliness which colour could in great part supply.

It was necessary for the creative designer to keep in touch with the thought underlying modernist changes. "No doubt," said the lecturer, "the large repeats of damask produced with expensive jacquard ties have precluded rapid and constant changes to meet fashion. It might be a matter of research to find types of pattern which could be produced on limited ties with a view to meeting the more rapid changes at smaller expense.

Finally the conclusion was put forward that there should be very close cooperation between the leaders of industry and the leaders of education. The leaders of industry would indicate their needs, and would help in various ways in the supplying of those needs. The educationist would consider the full extent to which education, without sacrificing its higher principles, could serve industry and help to bring forward the latent ability of the country towards a better state of things in the future.

After hearing a very interesting lecture, a vote of thanks to Mr. Dawson and Mr. Anderson was moved by Prof. Bradbury. Dr. W. H. Gibson seconded the motion, which was supported by Professor Earls, and heartily accorded.

NOTES AND NOTICES

Library Catalogue

The Library Catalogue referred to in the October issue of this *Journal* (page P165) is now available at the price of 6d. post free. Copies may be obtained from the Institute headquarters or from the Honorary Secretaries of Sections. The Library Committee expects that a marked increase in the use of the Library will be a result of the issue of this document, and members are asked to familiarise themselves with the rules set out in the catalogue. From time to time additions to the library will be recorded, and copies sent to all purchasers of the catalogue, who will be enabled in this way to keep up to date.

Journal Index

The index and title pages for 1930 will shortly be ready. All previous applications for his publication have been recorded, and copies will be sent to those on the list. Further requests should be made at once, as the number printed is limited, and reprints are too expensive.

Meeting of Council

At the March meeting of the Council of the Institute on the 19th inst., there was a good attendance under the chairmanship of Mr. Frank Nasmith, who welcomed Mr. F. S. Chance, of Carlisle, as the new representative of the area which is included in the Scottish Section. A leading item of business was the acceptance of the proposals of the Propaganda Committee in relation to the scheme of Scholarships in connection with which a fund of £5,000 was donated to the Foundation Fund last year by the Cotton Reconstruction Board. The Committee was authorised to proceed with the scheme on the lines indicated. It was reported that an inventory of the Institute furniture, fixtures, fittings, and other possessions at headquarters had been made by Messrs. G. F. Singleton and Co. Ltd., and the total amount of the valuation reached £3,800, apart from a small quantity of furniture, etc., at the London Offices at 104 Newgate Street, E.C.1. The valuation is for insurance and other purposes. The Lancashire Section Committee presented a report of proposed programme in connection with the annual general meeting of the Institute, which is to take place at Bolton on the 7th May next, and it is provided in the arrangements for the holding of the meeting at 11.30 a.m. at the Technical College, Mawdsley Street, luncheon at 1 o'clock and the Mather Lecture at 2.30 p.m., with a visit later to the Textile and Engineering Branch of the Technical College, assuming that arrangements can be effected accordingly. It was reported to the Council that twenty nominations had been received in reference to the election to fill ten vacancies on the Council, and instructions were given for the issue of ballot papers in due course.

Employment Register

In relation to the Institute's Employment Register, inquiries from employers as to the availability of services in various capacities have not come frequently to hand of late. Nevertheless, demands have occasionally arisen, and useful introductions of candidates for vacancies have been effected, and employers have been good enough to express their thanks to the Institute for the facilities afforded. A reminder of the existence of our Register may be useful at the present juncture, and the following cases of application for employment may be quoted—

No. 35—Age 37; A.T.I.; textile analyst and chemist; capable of charge of testing laboratory.

No. 34—Age 45 years; married; 25 years in sales branch of Bradford firm of manufacturers; visited Eastern and European markets; conversant also with buying of most classes of textile goods, and with shipment.

No. 33—Age 29 years. Many certificates in cotton spinning and weaving; prize winner in Institute Crompton Prize Scheme for woven fabrics; Associate of the Textile Institute. Seeks post as weaving manager, or in textile testing, or designing.

No. 32—Age 26; A.T.I.; B.Sc. in Applied Chemistry and Diploma in Dyeing. Six years with woollen cloth manufacturers, with full control of dyeing department, assisting also in supervision of other departments from raw material to finishing.

No. 31—Age 27. First-class education; three years of experience in chemical laboratories and conducted research on cellulose, textile fibres, oil, etc. Thesis—research on flax.

Institute Membership

At the March meeting of the Council, the following were elected to membership of the Institute—F. W. Atack, Kingston, Ontario, Canada (Consulting Chemist); R. Bankapur, 24 Swayfield Avenue, off Dickenson Road, Longsight, Manchester (Student); G. Carter, Salroyd Villas, Low Moor, Bradford (Student);

D. H. Bronnert, 56 Princess Street, Manchester (Student); W. Fairclough, 2 Highfield Road, Chorley (Cotton Mill Salesman); J. Hughes, 247 Chamber Road, Werneth, Oldham (Works Manager); J. B. Lancashire, 144 Kimberley Road, Leicester (Textile Teacher); R. S. Ledger, 7 Brooklands Terrace, Skipton, Yorks. (Chemist); E. Loth, 26 Zamkowa, Pabjanice, Poland (Manager of Textile Mills); J. E. Masters, P.O. Box 1976, Durban, Natal, S. Africa (Manager); J. V. B. de la Motte, Ashton Bros. & Co. Ltd., 29 Portland Street, Manchester (Secretary); Knowles Edge, Ribble Lodge, Lytham, Lancs. (Director & Chief Chemist).

REVIEWS

The Silk and Rayon Directory and Buyers' Guide of Great Britain 1930. Published by John Heywood Ltd., Manchester. (21s. nett.)

The 1930 edition again shows an increase in information over 1929—a noteworthy fact when taking into consideration that that year's amount of information was three times greater than the first edition in 1926. The present edition is largely due to the ever increasing number of firms using rayon yarns in the manufacture of both knitted and woven fabrics. That silk and rayon are employed in an immense variety of manufactured goods is indicated by the addition of 160 new sections to the Buyers' Guide. The alphabetical list of firms and index to the Buyers' Guide, both new features of last year's edition, were appreciated, and have been subjected to careful revision. The Directory is attractively and clearly produced, like the former editions, and a copy of the new issue should now prove a necessity each year to all those engaged in the industries for which it caters T.

The Cotton Year Book 1930. Published by the *Textile Mercury*. (Price 7s. 6d.)

The compiler of the Twenty-fifth edition of the Year Book points out that much of the revised information, especially in relation to Lancashire trade, proves depressing reading matter, though textile machinery makers, scientists, and the representatives of all research departments continue to bend their energies towards equipping the trade to meet modern requirements. The well-marked sections of the book eliminate the necessity for searching by the seeker of information. Mention cannot be made of all the sections, but the last one, in which lists are given of employers' and operatives' associations, is extremely useful. T.

The Textile Recorder Year Book 1930. Edited by John Brooks; published by John Heywood Ltd., Manchester. (Price 7s. 6d.)

Several new features have been incorporated in the 1930 edition of this Year Book. To cope with recent advances in the knitting industry, the Hosiery Section has been entirely rewritten. A new section is devoted to the winding of rayon, and describes modern methods of oiling rayon yarns for knitting. The chapters on humidification and ventilation have been considerably augmented. Other new features include a section on the procedure to be adopted in establishing trade marks, lists of holidays in textile districts, tables of logarithms and antilogarithms, and certain new tables of statistics. All standing matter has been carefully revised. T.

THE JOURNAL OF THE
TEXTILE INSTITUTE

Vol. XXI · APRIL 1930 No. 4

PROCEEDINGS

Lancashire Section

Meeting at the Technical School, Preston, on Friday, 24th January 1930; Mr. J. Hollas presiding.

THE WEAVING OF ARTIFICIAL SILK

Mr. J. Starkie, Head of the Textile Department, Nelson Technical College, delivered an address on the above subject to a large and interested audience. The duration and character of the questions and discussion which followed the lecture were adequate testimony to the keen attention paid to what Mr. Starkie had to say.

The lecturer pointed out that the introduction of rayon yarns into the weaving sheds of Lancashire had imposed the adoption of new methods and devices differing from those for cotton since the new material was itself of a different nature. It was to the credit of Lancashire that many excellent fabrics, woven either in part or entirely of this new material, had been made on cotton looms adapted for the purpose. The machines specially made for weaving rayon, though capable of producing first-class fabrics, were difficult to install in the normal Lancashire weaving shed because of their unusual dimensions

Mr. Starkie next described the properties of rayon yarns and compared these with the properties of cotton yarns. He warned his audience that the greatest care must be taken to avoid the breaking of the individual filaments of which rayon yarns are composed. As the strength of these yarns is materially affected by moisture, and as this necessitates weaving conditions diametrically opposed to those for weaving cotton, it was impossible to secure ideal conditions to weave the two types of yarn in conjunction. The absence of elasticity and the high capacity for extension in rayon yarns implied particular care in tensioning and in other directions. These precautions, the lecturer pointed out, were not so necessary when handling acetate rayon which was not so affected by moisture and tension.

The lecturer turned particularly to the weaving of rayon as *warp* and described the points in the loom which needed special care before setting out to weave rayon. A perfect traverse of the shuttle is necessary; a new race board may be needed; box plates should be cleaned and smoothed, and the shuttle race should preferably be covered with swansdown or ribbed pile cloth. The reed should fit firmly in the sley; shuttles in good condition are needed; and it is advisable to run the loom for a while without warp in order to study the shuttle movement. Considering the yarn itself, Mr. Starkie urged that paper be used in preparing the beam so that a firm beam may be secured and the correct position of broken threads easily discerned. The position and weighting of the warp beam and back rest were next discussed and advice given as to the best arrangements. It was an advantage, said Mr. Starkie, to use wire healds knitted to the staves with small eyes set at an angle of 45°. Shedding next came under consideration, and it was advised that a late shedding, in accord with common Lancashire practice, gave a less open shed than desirable. Much depended upon the fabric being woven, and experience would indicate suitable settings in separate cases. It

was difficult to obtain temples which would hold out the cloth adequately and not mark the fabric. No special make could be recommended and some successful looms were to be had with no temples at all. A taking-up roller of large diameter was advocated with guide rollers and a cloth roller driven by a slipping friction.

The weaving of rayon stripes came next under notice, and Mr. Starkie pointed out that the yarn is usually separately beamed and placed above the warp line with a guide roller behind the back-rest. In this case cotton healds may be used for the ground warp and wire healds on a good slider for the rayon. Use a tappet shedding for the ground weave and a dobby for the stripes. The same advice was given again as to shedding, and it was urged that weavers should do everything with a view to reducing friction on the yarn and to allow a perfect shuttle traverse.

Considering the weaving of rayon as *weft*, the lecturer pointed out that a shuttle was required that would hold the pirn securely and give the required tension as the yarn was drawn off; fur lining would give control during unwinding and a worsted tuft or mop in the eye would give the required tension. Various types of shuttle tongues were described and their merits and demerits discussed. Examples were shown and handed round. Shuttle box fittings were to be given special care and points to observe were detailed. Picking speed and strength was referred to and faults arising from undue tension, weft breakage, etc., were explained. Automatic measuring devices, stop-motions, and weft-mixing arrangements each had the attention of the lecturer, whose remarks, illustrated by black-board diagrams, were clear and precise.

Mr. Starkie then proceeded to describe the advantages of looms specially designed for weaving rayon. The reduced vibration gave improved starting, increased cleanliness, and provided better checking devices and take-up arrangements. These looms, though very efficient, were expensive, and on this account the lecturer felt that it would be to the modified existing loom that Lancashire would turn at the present time.

Discussion

The Chairman, calling for questions and discussion, asked for brevity, as he was sure many questions would be put after such a practical and interesting address. The following list of questions is not by any means complete nor did time permit of every question being advanced. A cordial vote of thanks to Mr. Starkie concluded the meeting.

1—*In which direction is a spiral cut on the spiral roller referred to by the lecturer as suitable for take-up motion?*

In some looms a stationary roller is used in place of the usual breast beam, spirals being formed at each end in opposite directions and in the direction which tends to increase the width of the fabric. In other looms the roller is free to revolve.

2—*Are rayon counts as regular as cotton counts?*

Providing that tension during preparation is uniform and that the production from the various machines is not mixed, rayon yarn should be as even in count as cotton, but unevenness does occur, both in count and appearance, the use of weft mixing motions being necessary to overcome this difficulty.

3—*Would the lecturer prefer emery or rubber covering for temple rollers?*

Rubber-covered rollers are better than emery-covered, because the surface is not so rough, and particles of emery often become attached to the fabric, causing trouble in finishing.

4—*How should emery covering be put on the roller?*

The surface of the roller is first made smooth, often a layer of cotton cloth is fixed, then the surface is coated with glue and rolled on a table covered with emery dust to a depth of about ¼ in. The first coat is allowed to dry and the operation repeated until the desired surface is obtained.

5—*Could the lecturer say what percentage of rejects would be reasonable for various types of fabrics, such as raydechine, warp satins, etc.?*

From a practical point of view, a reasonable percentage could not be estimated. This would depend on the type of loom employed and the length of time the firm had been engaged on the particular class of work. The percentage would decrease with experience.

6—*Can the lecturer explain why bright picks appear in groups at irregular intervals?*

The appearance of bright picks in groups would suggest variation in tension during winding; it is unlikely that tension in the shuttle would increase for a period and then be reduced to normal.

7—*Has the lecturer experience of a shuttle with a centre eye or information as to its advantage or disadvantage?*

I have never tested a shuttle with a centre eye, but the fact that this type of shuttle is very little used for rayon weft would suggest that very little advantage is to be obtained by its use. With the ordinary type of pirn it would be more difficult for the weaver to thread the shuttle and any advantage gained would probably be lost in other ways.

8—*Would the lecturer recommend the use of a fast or loose reed?*

A fast reed loom is usually preferred because the reed is more rigid and the loom is built on substantial lines, on the other hand, with a loose reed loom, less difficulty is experienced with the picking motion and rayon weft is easier to handle. For plain fabrics, a good loose reed loom, heavily built, will give quite as good results as a fast reed loom, with a smaller cost of upkeep.

9—*Speaking generally, is it right to suggest that the Continental loom specially made for weaving rayon overcomes most of the difficulties described?*

A Continental loom specially built for weaving rayon will overcome many of the difficulties, because it has been designed for that purpose and with the defects of the cotton loom in view, the loom will produce cloth as good or better than the Lancashire loom with less skill on the part of the weaver.

10—*What is a reasonable tension to insert on warp yarns in rayon weaving?*

The warp tension during weaving should be such that the yarn is not stretched beyond the limit of elasticity. For plain fabrics, the cloth length should be approximately 5% less than the warp length; if more length of cloth is obtained, permanent stretch has taken place, and this indicates excessive weighting.

11—*To what extent is uneven sizing the cause of weaving trouble?*

Uneven sizing will cause broken filaments to appear in the warp shed, due to these filaments not being held together by the size. It is often difficult to determine whether the broken filaments are due to loom defects or to faulty sizing. During recent years sizing has improved to such an extent that it is mostly faulty loom settings that are responsible, and these should be thoroughly investigated before complaints are made regarding sizing.

Yorkshire Section

Joint Meeting with the Cartwright Club at Leeds University, on 4th February 1930.

SOUTH AFRICA AND SOUTH AFRICAN WOOLS

In the course of a lecture on his visit with the British Association to South Africa, Professor A. F. Barker first referred to the history of sheep in South Africa, more especially to the merino stock. It appeared possible that certain areas in the Transvaal, in South Rhodesia, and in Kenya Colony might be rendered suitable for merino sheep all the year round. Pasturage was of three types—karoo, mixed veld, and grass. These were described, and their advantages and modifications needed discussed. The possibility of a sheep migration system

in areas not capable of maintaining a sheep population the year round was postulated. Professor Barker next referred to rainfall and its periodicity in relation to the lambing season. He urged that the "distribution" of rainfall, not the "absolute" rainfall, might be the important matter. He pleaded for thorough examination of meteorological conditions in South Africa and proper recording of data and training of suitable men. Such studies and records would include consideration of "temperature," he urged, and perhaps with reference to wool-growing the *minimum* temperature at all likely on any sheep station was the important matter. After a brief reference to fencing, the lecturer described the races of South African sheep. Two races—the broad-tails or fat rumps and the merino—are the basis of South African stock. Particulars were given of the wools produced and the selection methods next came under notice, and particulars as to diameter, crimps, and fibre lengths from the main divisions of the fleece were given for native stock and for Cape merinos. Reference was made to the potentialities of Cape wools and to the defects from which they now suffer were enumerated. Sheep dips, adjustment of race to environment, and the economics of farming next came under review. In conclusion, Professor Barker dealt with the technical requirements of the wool industry from the point of view of the wool grower who has to meet, or attempt to meet, the needs of the manufacturer. The possibility of even lighter fabrics being required—even as light as 4 oz. per yard—was advanced, and to produce such fabrics two suggestions were made—To produce a "square" (uniform fibre length) top of comparatively short wool and spin it on the cotton method, or to spin short fine wool with a certain percentage of cotton, and in the finishing carbonise the cotton. The potentialities of the "square" top had been noted, and experiments made in the University (Textile Department) had shown the impossibility of producing a regular yarn from a "non-square" top. It was postulated by the lecturer that wool should be grown as uniform as possible, and sheared at its optimum length. During long growth periods the variation in length is far greater than after shorter periods. Consideration of the problem being further developed, the lecturer urged that the South African farmer, to meet these requirements, would have to (*a*) select his sheep for regular growth of wool in length, and (*b*) shear his sheep at periods in conformity with the climatic conditions, but giving at the same time the nearest approach to the optimum growth period. The lecturer now pleaded that the most important matter for perfect yarn and cloth structure is uniform length of fibre. He concluded by picturing the effect upon the industry as a whole of the establishment of this new conception of wool production.

London Section

Meeting at the Institute's London Rooms, 104 Newgate Street, on 13th February 1930, Mr. S. A. Williams in the chair.

THE JUDGING OF TEXTILES

By W. C. Whittaker, F.T.I.

This is a very big subject, because the word "textiles" itself covers such a tremendous range of merchandise. If one thinks for a moment of the materials used in clothing a crowd, one is amazed at the variety which one can see, and can only guess at the number of other garments which one cannot see. Textiles, of course, are also used in most things, like motor cars, trains and ships, in industry either in process or as containers. This lecture is a consideration of some of the major differences in connection with ordinary merchandise and clothing.

Wool

A blue serge for any given weight may start at a few shillings per yard, and gradually work up grade by grade to about 16s. per yard, the difference being

one entirely of quality. The yarns are as strong, sometimes stronger, in the lower grades than in the higher grades. The wool fibre is usually longer in the lower grades than the higher grades. What, then, is this difference that makes for the difference in price? It is the quality of the wool used. In the higher grades it is finer in fibre, softer to the touch, and more pleasant in the appearance, i.e., 2/24 of 44's quality is 2s. per lb.; 2/24 of 60's quality is 3s. per lb.; 2/24 of 70's quality is 3s. 8d., and it is these differences of the quality and fineness of wool that go to the making of the price.

Very often the lower grade yarns consist of the longer fibre, and there is a general misunderstanding in the drapery trade about the length of wool, fibre, and quality. The finest merinos are not long fibred wools compared with the coarser qualities. In fact some of the finest and highest grade wools are rather short in fibre, whilst some of the cheaper yarns like Lincoln and Leicester have very long fibres indeed.

Linen

The fineness of fibre and yarn has a great influence on the cost and quality of the finished article in linens. For example, a 60's lea warp is 8s. 1½d. per bundle, whilst 120's lea is 9s. 3d. This in weight is 60's at 2s. 5½d. per lb.; 120's at 5s. 6½d. per lb.

Take this a little further, and consider cambric handkerchiefs. We will take a 12°° and a 24°° cambrics and 24″ cloths. The price for 12°° would be about 8s. per dozen, whilst that for 24°° would be about 21s. per doz. Both prices for shire hemstitched. This increase in price is due partly to quality of yarns and partly due to extra work involved. It should always be remembered that the picks or shots of weft per 1″ or other measure bear a direct relation to the cost of weaving. For example, a cloth with 134 picks per 1″ will take twice as long to weave as one of 67 picks per 1″.

Cotton

Cottons, like linens, increase in value with fineness of yarns, and two-fold yarns replacing singles of the same size. For example, a cloth made of 60's combed single Egyptian cotton would cost about 36d. per lb., whilst 2/120 yarn to replace it would cost over 5s. per lb. The latter would have a better and clearer effect in a poplin, especially as a weft. The double yarn gives a more regular rib than the single yarn. The extra cost is due to the actual spinning length of the yarn being twice that of the single and usually a much better cotton is used for 120's than 60's.

Silks

Silks more than any other textile fibre show a direct increase in value to the increase in weight. Whereas in linens, cotton, and woollens any increase in weight is usually balanced by coarser yarns from slightly inferior fibre. This, of course, is speaking generally, as there are many exceptions both ways. A good quality of thrown silk is, say, about 27s. to 29s. per lb.

Hosiery

A hosiery manufacturer will often use the same quality for 6, 8, 10, and 12 thread hose, so that the value of the stocking increases with the weight of silk or threads used. So, roughly, we could say that a 10-thread hose would be 70s. per dozen, an 8-thread 62s., and a 6-thread 54s.; all made of the same quality silk, the difference being the number of threads of, say, 13/15 denier silk taken for knitting. Sometimes two threads of 4-thread or of 5-thread silk is taken instead of one 8 or 10-thread which gives a better cover. The figures given are comparative, and naturally vary with the length of silk panel, the gauge and courses, but I want you to realise just where the difference in price comes from.

In hosiery, open or lace clock costs 3s. to 4s. per dozen extra. An embroidered clock say 6s. to 12s. per dozen, the latter hand embroidered. To give a silk

over welt may cost from 4s. 6d. to 10s. per dozen, according to threads of silk used and the depth of welt.

These remarks refer to fully fashioned hose, and I want now to say a few words about the difference between mock fashioned and fully fashioned goods. The mock fashioned hose is made on a circular machine, and is really seamless. The seam is afterwards put in to give effect. It is sometimes stated that it is difficult to tell the difference between fully fashioned and mock fashioned hose, but anyone with a little training can tell the difference ten yards away, and, roughly, one can say that a fully fashioned stocking costs 50% more than a mock fashioned one. So you will see that the difference is an important one. Again, the thread used in a mock fashioned stocking is of importance. For example, a 6 thread stocking may be 36s. per dozen, whilst an 8 thread would be 41s.

There are two types of mock fashioned or seamless hose—spring needle and latch needle. The spring needle machine gives a better shaped stocking than the latch needle. This is due to the automatic tension which allows large loops to be made at the top of the stocking and fine loops at the ankle. It is used for better qualities, and the extra cost of working is 1s. to 2s. per dozen. Seamless hose is spoken of by the total needles used, i.e., 260 or 300 needle stocking. A French or Continental foot has a seam on the bottom of the hose, whilst an English foot has a seam on each side of the foot. In my opinion the Continental foot has a better appearance.

Silk Fabrics

In hosiery good thrown silk is about 28s. per lb. It is possible that a lower grade would cost about 20s. per lb., and such a weft might be used for a cheap crêpe-de-chine. A poorer type of weft can often be seen by holding the cloth against the light, and the irregularities of the yarn may be compared with a better quality. Crêpe-de-chines vary in cost with the texture, weight, and quality. A rough average cost to-day is about 4s. 2d. per oz. based on one ounce of pure silk in the fabric. The increase in cost would be less than that in heavier types, and it would work out about 3s. 10d. per ounce. For the lower the weight, the greater the relative cost of manufacture.

Fashion and Design

There are certain classes of merchandise which cannot be valued in terms of material and cost of actual manufacture. I refer to fabrics and garments produced by artists such as Rodier and Jean Patou. The work of such firms cannot be judged by ordinary standards. The efforts and overhead costs of such businesses are tremendous, and the actual selling value depends on the name of the maker and fashion value of the article. It should also be remembered that the value of such goods only lasts for one season. Many English and Continental firms spend small fortunes in producing ranges of designs, that is, in the wages of designers, and the carrying through of the samples and card cutting, etc.; all these expenses must, of course, be added to the cost of the finally selected range for the season, and even with the best brains in the world on that type of work, there have to be many rejections to get a perfect or even interesting range of designs, either fabrics or garments.

TEXTILE LABORATORY

Checking and Testing

This is a subject that no doubt you are interested in, and as time goes on more and more stores and businesses go out for this so-called "research" work. As a matter of fact it is not research work at all, but the application of manufacturing truths to the wholesale and retail businesses. We are often told that such a decision is scientific; possibly it is, but remember that it is matter-of-fact knowledge to the manufacturer, and such facts are essential before an article

can be made in the mill or workshop, so that checking of price, quality, and understanding the market is not anything really new, but the application of knowledge that already exists in the different branches of manufacture and commerce. A thorough knowledge of the conditions of the markets is essential in any large business; you always find that all the buyers know when the market is rising, because everyone who has something to sell makes it his business to tell them. Whereas when the market is falling, sellers keep it quiet.

When a testing laboratory is started in any business, it is looked upon as very theoretical, and we believe that the only real way to get over that feeling is to have someone with practical manufacturing experience in charge. A textile laboratory is useful first in getting correct comparisons and values of merchandise, and when a buyer is used to it, he knows exactly what has happened, should a quality be changed by the manufacturer. It is also useful for investigating complaints and for calculating fairly accurately how much the change in market conditions should change the cost of an article.

There is a wrong attitude amongst buyers generally with regard to merchandise; they think it very undignified to investigate thoroughly the qualities of an article. They believe that "snap" judgment is clever. In some cases a quick judgment is very clever—if it is backed by knowledge. But you have people without any real training or manufacturing knowledge making statements about merchandise after a moment's examination which a manufacturer who thoroughly understands the business would never dare to make without full investigation. The more one knows about structures and qualities, the more careful you will be before giving a quick reply. I believe that if buyers and those interested in the trade would apply more simple tests to offered merchandise, without being ashamed, we should get less bluffing and more commonsense into business. It does not always mean a laboratory with chemical and physical appliances, but the use of a box of matches and a pocket lens, and a little practice would change guesswork into facts.

Selling Price

A buyer should always have some idea of his selling price when purchasing. That is, he should always be able to determine a price which his particular clients will pay for that article. Some firms insist that when an order is placed, the selling price is marked on the retained copy of order, and this cannot be altered without permission of the merchandise manager. All this, in our opinion, is good, but some people carry the idea further and buy to a price. This, as a general principle, is wrong, unless you have a buyer who thoroughly understands the manufacture of the merchandise in question, and is a very good man on actual values. Suppose it had been decided to sell a dress at 80s. (some firms would prefer 79s. 11d.), and the rate of profit was 25%, the buyer would go round asking for something at 59s. or 60s., and there is a tendency for some buyers to refuse an article at 50s. or 55s. because it is too cheap in price, although the actual value may be greater than a garment offered at 59s. or 60s. This may sound rather ridiculous, but I can assure you it often happens in practice.

Some wholesalers and manufacturers play up to this weakness of buying policy, and do not fix their selling prices on the economic basis of production and profit. You notice the effect of this when a wholesaler's prices are fixed in such a way that it just allows 25% or 33⅓% when selling at some well-known price like 3s. 11½d. A very common wholesale price is 2s. 11½d., which allows about 25% when selling at 3s. 11½d.

The same idea has influenced certain making-up centres which offer garments to the retailer at prices like the following—59s. 11d. to sell 79s. 11d., and similar quaint figures for a house that likes 25 per cent. On the other hand, if the wholesaler knows you are a 33⅓% house, he has a garment at 39s. 11d. for you to sell at 59s. 11d., and so on. Now I submit that many of their prices are not

based on standard costings of materials and making, plus the profit, but are prices arranged to meet the idiosyncrasies of the average retailer.

THE ECONOMICS OF PRODUCTION

I will go a little deeper into this question of "buying to a price," and what I wish to explain about manufacturing is this—that in the manufacture of all kinds of utility articles there are the same economic principles present as in the case of making a Morris or a Ford car. To illustrate this, we will take a high grade fully fashioned ladies' hose retailing at 8s. 11d., and costing 76s. per dozen (6s. 4d.), which allows about 29% profit. The buyer, thinking in selling terms only, decides that 9s. 11d. would be a good selling price for the same type of stocking in a better quality. His overhead and advertising charges make it essential that he should have about the same profit as before (i.e., 29% or 30%), which would mean buying at about 84s. per dozen. The buyer goes to the manufacturer and says he must have a stocking at 84s., made on the lines of the 8s. 11d. hose, but of a better quality. No doubt the manufacturer will supply one, but the questions are—will the new hose be made on an economic basis? Will the retailer be giving the public as good value (relatively) as in the 8s. 11d. line ?

Now we will leave the buyer with his "fixed price" and consider the manufacturer's side of the same question. In a well-organised factory the yarns are carried in certain sizes, i.e. counts, deniers, or whatever you like to call them. We will assume that this manufacturer stocks 8-thread, 10-thread, and 12-thread silks for hosiery (which is a very common practice). The 8s. 11d. hose is made from a 10-thread silk, therefore his next best quality should be made from a 12-thread silk. If the cost of the 10-thread silk is 76s., the cost of the 12-thread would be about 90s., with a retail selling price of 10s. 9d. (not 9s. 11d.). Therefore this manufacturer could not make a stocking at 84s. on an economic basis, as he would have to use 11-thread silk. I am not sure that I have made my point clear, but what I have been trying to say is that the merchandise should be considered first, and the possible selling price fixed after.

Discussion

The lecture was followed by a discussion in which several members of the audience spoke. The Chairman assured Mr. Whittaker that his address had been much appreciated, and a hearty vote of thanks attested to this.

Scottish Section

Annual Meeting, North British Station Hotel, Edinburgh, Saturday, 8th March 1930.

Mr. Thomas M. Lees (Galashiels) presided, and although the attendance was not large, it was representative of all districts. The Chairman expressed his pleasure at seeing Mr. J. D. Athey (General Secretary) present, and hoped that he would soon be restored to good health.

After reading the notice calling the meeting, and intimating apologies for absence, Mr. A. W. Blair (Hon. Sec.) presented a report covering the period from 1st March 1929 to 28th February 1930. The membership totalled 82 at the commencement, and at the later date they had lost 5 members, two through death and three by resignation. The total, including new members, was now 80, distributed as follows—East and Midlands, 29; Border district, including Carlisle, 28; West and South-west, 20; North, 3.

Five Section meetings had been held, at Edinburgh, Perth, Glasgow, Jedburgh, and Galashiels respectively, and he took the opportunity of expressing on behalf of the Section Committee sincere thanks to the various lecturers and those whose services had contributed to the success of the meetings.

For the information of members, he presented a summary of disbursements made by the Section Committee during the season, pointing out that no actual

balance sheet was necessary, since annual subscriptions were remitted direct to the Institute, which in turn paid the administrative costs of the Section. The total sum expended during the year was £7 3s. 6d., equivalent to 1s. 9½d. per member.

The report was adopted, and Mr. Blair was heartily thanked for his services. The Chairman said they were extremely fortunate to have the services of Mr. Blair, and he hoped they might have the privilege of continuance for many years to come.

Mr. Blair acknowledged the thanks, and said he could not allow that opportunity to pass without acknowledging the assistance and encouragement he had always received from headquarters.

The General Secretary (Mr. Athey), in moving a vote of thanks to the retiring Committee, said the Council appreciated greatly the earnest endeavours of the Section Committee. The difficulties of the Section owing to the long distances between the districts of the area were fully appreciated.

Regarding the constitution of the Section Committee, it was decided to recommend to Council the election of three members together with the Hon. Secretary—Messrs. J. Macpherson Brown, Galashiels; A. R. Geary, Dunfermline; and T. M. Lees, Galashiels. It was agreed to nominate Mr. Brown as Chairman, and Mr. A. W. Blair as Hon. Secretary.

The question of submitting a nomination for the Council of the Institute was considered, and Mr. Black (Dunfermline) moved that Mr. J. P. Beveridge be nominated for a further period. Mr. Lees seconded, and on Mr. Beveridge agreeing to accept nomination, it was decided to circularise members endorsing his nomination.

With regard to the programme for next session, it was agreed to endeavour to arrange a visit to Paisley and to Dunfermline; in the latter connection Mr. Black said he would be pleased to arrange for the entertainment of the visitors.

The question of the contribution of papers by Scottish members for the Institute's coming-of-age celebrations (1931) was referred to the Section Committee.

A hearty vote of thanks to the Chairman concluded the meeting.

Irish Section

Annual Meeting, Municipal College of Technology, Belfast, Friday, 28th March 1930.

Dr. W. H. Gibson was voted to the chair, and the minutes of the third annual meeting (22/3/29) were read and passed.

The Hon. Secretary, in presenting the annual report, stated that during the past session three meetings had been held at which papers had been delivered as under—

5th December 1929—"Pedigree Flax Seeds," by G. O. Searle, B.Sc. (Agric.), of the Linen Industry Research Association.

23rd January 1930—"Costs and Statistics for the Linen Trade," by J. F. Whiteford, M.A.S.M.E. (of London).

13th March 1930—"Style, Fashion, and Modernity in Textile Design," by R. A. Dawson, A.R.C.A. (Lond.), F.S.A.M.

The meetings were well attended, and much interest taken in the subjects chosen. The thanks of the Committee were due to those gentlemen who so ably contributed papers, and to the Principal of the College (Mr. Earls) for facilities afforded for the holding of meetings. During the past year two new members were received, also two resignations, so that the membership of the Section still stood at 34.

The report was approved, and it was decided that Chairman, Hon. Secretary, and Committee be recommended to Council for re-election as follows—Chairman, Mr. W. H. Webb; Hon. Sec., Mr. F. J. W. Shannon; Committee—Dr. Gibson, Prof. Bradbury, Messrs. F. Anderson, R. Stevenson, W. J. Cowden, J. Kirkwood, and G. R. Beatty.

After discussing several subjects suitable for lectures for next session, it was decided to leave arrangements for same in the hands of the Committee.

NOTES AND NOTICES

The Annual Meeting

Members, who will have received notice of the event before this issue appears, are asked to notify attendance as soon as possible in order to facilitate the luncheon and other arrangements for which a knowledge of the probable attendance is desirable. The meeting promises to be noteworthy in more than one direction. The municipality of Bolton has extended a welcome to the Institute through the kind invitation of the Mayor, Councillor R. E. Roberts. The occasion is also to be marked by the delivery of the annual Mather Lecture. The first of the series was contributed by John A. Todd in 1919, and the list of those who have addressed the Institute as Mather Lecturers now contains names of which the Institute may be justly proud; that added this year promises to maintain the high standard already secured. The subject is perhaps ambitious, but none the less necessary, since it never was more important that the industry should take a broad view of the immediate future. The Council's decision to award further medals this year has given much satisfaction, and the recipients' efforts over many years on behalf of the Institute represent a measure of personal sacrifice difficult to estimate, but which may best be gauged by the present position of the organisation for which they have so generously and continuously worked. No note on this event would be complete without placing on record the thanks due to the Education Committee of Bolton and to its officials; the Technical College in Mawdsley Street has been placed at the Institute's disposal, and arrangements made for members to visit the Textile Department of the College in Bridgman Place.

Institute Rooms and Library

The attention of members is drawn to the facilities available in the Institute premises. The Library is now mainly contained in the Members' Room, which offers good accommodation for reading and writing. Lunches and teas may be obtained throughout the week, but for lunch it is advisable to give preliminary notice. The number of volumes available is steadily increasing, and many of the earlier difficulties of housing accommodation have been overcome by the adoption of various proposals put forward by the Library Committee. Books, journals, and pamphlets may be borrowed, as will be seen from perusal of the Library Catalogue, which is now obtainable at the price of sixpence per copy. There is also a small room at headquarters which by arrangement may be utilised free of charge by members for private interviews, etc. The London offices of the Institute at 104 Newgate Street, EC.1, offer a well-appointed writing and reading-room for use by all members, with telephone and other facilities.

Mounted Abstracts for Card Indexing

Attention has previously been drawn to the advantages to be derived from the formation of an abstracts card index. For the benefit of new members and those who did not see the previous note on the subject, the particulars are again given. The Abstracts Section can be supplied each month, printed on

one side of the paper, for the annual sum of twelve shillings. The items can then be mounted separately on cards. The charges for dry-mounting are quite reasonable, and full particulars of the system can be obtained from the Institute or from the firm who undertakes the work, and whose advertisement appears from time to time in the *Journal*. (*See* page *xii*, March issue.)

Textile Institute Diplomas

Election to Fellowship and Associateship of the Institute has been completed as follows since the appearance of the previous list (February issue of this *Journal*).

FELLOWSHIP

BUCKLEY, George Hervey (Nottingham).

ASSOCIATESHIP

CRABTREE, John Leslie (Halifax).

Institute Membership

At the April meeting of the Council the following were elected to membership of the Institute—A. F. Aupetit, "Lyndene," Wigan Road, Bolton (Textile Student); B. D. Breuning ten Cate, High Lawn, Sharples, Bolton (Textile Student); S. Czerkaski, 5 Bromwich Street, Bolton (Textile Student); A. R. B. Dobson, 8 Ducie Avenue, Bolton; A. Fairgrieve, Abbots croft,Galashiels (Woollen Yarn Manufacturer); H. E. W. Forelius, 66a Radcliffe Road, Bolton (Textile Student); A. W. Fowler, 180 Outram Street, Sutton-in-Ashfield, Notts. (Hosiery Dept. Manager); W. Howcroft, The Black Lane Mills Co. Ltd., Radcliffe (Managing Director); T. Lloyd, 13 Waugh Avenue, Failsworth, Manchester (Textile Draughtsman); E. L. Milliken, c/o Waypoyset Manufacturing Co., Box 972, Pawtucket, R I., U.S.A. (President and Treasurer); J. F. Quick, 34a Denning Road, Hampstead, London, N W.3 (Cotton Piece Goods, Apprentice); W. Walker, 1 Princess Road, Shaw, Lancs. (Student).

COMMUNICATION

"Cloth Spiders" in a Grey Cotton Piece Warehouse

To the Editor

Sir

I was recently asked to investigate a case of infestation of a grey cotton piece warehouse by what was called a "cloth spider," and which I found later is also known amongst warehousemen as a "cloth bug." It is neither a spider nor a bug, but a beetle, *Niptus hololeucus*. It is a light brown insect, resembling a small spider, but readily distinguished from a spider by the fact that it has six legs, whereas a spider has eight, though the long many-jointed antennæ may at first glimpse be taken for a pair of legs. In addition, on crushing the insect it will be found to have a hard body, whereas that of a spider is soft.

It is a very common insect, and is stated to be omnivorous, but I have no knowledge of it being a textile pest. In this case the beetles were presumably living on the size from the fabrics, but no damage had ever been caused by them. Curiously enough the heaviest sized fabrics were free from the beetles, which had an especial liking for a medium-sized rather loosely woven cloth, perhaps because they were able to move about more freely in the latter than in the former.

Even though they caused no damage, customers naturally refused to accept cloths infested with these insects, and the warehousemen similarly objected to their presence, though they are harmless to human beings; they are, in fact, a nuisance not a pest, though doubtless, given suitable conditions, they could develop into a pest. The best thing to do on finding them in a warehouse is to have the whole place fumigated by one of the firms specialising in such work.

22 Willowfield Crescent, Wrose Road (Signed) C. O. CLARK.
Bradford, Yorks., 7/4/30.

REVIEW

The Worsted Industry. By J. Dumville and S. Kershaw. Published by Sir Isaac Pitman & Sons Ltd., London. (139 pp., price 3s.).

This little book, one of the publishers' well-known series on Common Commodities and Industries, gives a clear outline of the worsted industry from the raw wool to the piece as it comes from the loom. The subsequent processes of dyeing and finishing, in many respects characteristic of the industry, are dismissed in the last half-page. In fact, cloth manufacture as a whole, or as the authors neatly describe it "from length to area," gets a small share, a matter of sixteen pages sufficing for the warping processes, tappet, dobby, and jacquard looms, and some notes on design. Certainly these are matters common to all branches of the textile industry, and in the same series there is a book dealing exclusively with weaving and others on wool, cotton, carpets, and jute, which a reader in search of wide and elementary knowledge of textiles should read. After all, the typical peculiarities of worsted manufacture lie in the spinning processes, and these are well and thoroughly done for so small a book. A chapter is given to wools, and one to wool scouring. The diagram and description of the Noble comb is more lucid than is often found in more pretentious books, and if the description of the French comb is somewhat brief, and those of the Lister and Holden combs difficult to follow without diagrams, the reader at least learns that such combs are used by certain sections of the industry. The descriptions of drawing machinery are well balanced between the characteristically British types and the less common but commercially important Continental types, while cone drawing comes in for about a page. The particular spheres of application of cap, ring and flyer frames and spinning mules are discussed, and the yarns produced by the various machines described, but the authors are less at home in dealing with the theory underlying the spinning processes. It is not, as they state, centrifugal force which winds the yarn on the bobbin in cap spinning, but the air resistance to the loop of yarn as it flies round the cap, centrifugal force playing but a subsidiary part. In treating of ring spinning, they say there are two forces acting on the traveller, centrifugal and centripetal. This is misleading, for the terms are but two ways of stating the same dynamical fact, that a body moving in a circular path tends to fly radially outwards as if acted on by a centrifugal "force," and requires the constraint of a centripetal force if it is to move in a circular path. The forces acting on the traveller are much more complex than this brief sentence indicates. There is an appendix in which the worsted processes are scanned from the point of view of a fire insurance expert, and a glossary. A bibliography of more advanced books would have been a useful addition. The book is not, and does not pretend to be, an exhaustive treatise for the man in the industry, but for the man outside the industry, or the beginner in it, the book provides a thoroughly reliable and readable guide. A.W.S.

THE JOURNAL OF THE
TEXTILE INSTITUTE

Vol. XXI MAY 1930 No. 5

PROCEEDINGS

TWENTIETH ANNUAL GENERAL MEETING

A BOLTON EVENT

By the courtesy of the Bolton Education Committee and of the Director of Education, the Twentieth Annual General Meeting of the Institute was held in the Mawdsley Street Technical College, Bolton, on Wednesday, 7th May 1930. Duties in connection with the International Federation of Master Cotton Spinners' and Manufacturers' Associations prevented the attendance of Mr. W. Howarth, immediate Past-President, and in his absence Mr. Frank Nasmith (Chairman of Council) presided. He was supported on the platform by Lieut.-Col. B. Palin Dobson (President-elect); Col. F. R. McConnel (Past-President); Messrs. W. Frost (Hon. Secretary), W. W. L. Lishman (Hon. Treasurer), and T. Fletcher Robinson. Over sixty members were in attendance, while numerous letters of apology for absence were read.

The Minutes of the previous Meeting, held at Bradford (11/4/29), were approved.

Mr. G. Clapperton, moving the Annual Report, stated that the document was most interesting reading. The items were clearly defined and the subject was well worthy of notice. He did not think he could single out any subject, except to pay a tribute to the *Journal*, which was of very great value to every member of the Institute whether he attended the meetings or not. The ordinary non-technical reader could understand the *Journal*. There had been an improvement in the direction of plain writing. It behoved every member of the Council to see that the most up-to-date information was circulated so that every mill might capture all the trade they could for Lancashire's benefit.

Mr. W. B. Richardson seconded, and said that the report struck him that the diversified interests of the Institute must be to the great benefit of the trade generally. He made an appeal for efforts to increase the membership.

The meeting adopted the motion by unanimous vote.

COUNCIL'S ANNUAL REPORT

Although during the past year the efforts of the Council have been chiefly directed to the advancement of well-established forms of Institute activity, yet the record of endeavour embraces additional movements of considerable importance. In view of the expansion of the application of science to the textile industry, it was decided to hold a week's exhibition of optical and other instruments in relation to textile technology during last July. The display was organised, as stated in a foreword to the catalogue, to stimulate interest in the utilisation of scientific instruments in the industry and to provide an opportunity for the manufacturers of high-class instruments to demonstrate the capabilities of their products. The exhibition, distinctive in character, was undoubtedly successful and many of the participators subsequently expressed their warm appreciation of the enterprise. Special provision was made for the attendance of parties of students from the various technical colleges and schools, and on several days the exhibition was open to the general public. Another special effort

has been in connection with the Library of the Institute. It is fully realised, however, that a library fitted to the requirements is still in an early stage of upbuilding, and advancement will continue as circumstances allow.

Standardisation of Testing

The Research, Testing, and Inventions Advisory Committee is to be congratulated upon the completion of a serviceable instalment of work in relation to standardisation in the testing of textiles. The attention of the Committee having been called to the publication of erroneous figures for conversion of the denier of artificial silk or rayon to other count systems, considered the whole situation and issued a report on the basis for determination of the denier and conversion. The report has been circulated to official and other quarters, and inquiries for further copies since received cover so wide a field as to leave no doubt of the usefulness of the document.

Revenue Account

In the last report, attention was drawn to the fact that the Revenue Account disclosed a small deficiency. As the expenditure included items regarded as non-recurring, however, the hope was expressed that the next financial statement would reveal a recovery. That hope has been fully realised. Notwithstanding the improvement in the financial position, a problem which may considerably affect the future has arisen owing to a new demand on the part of the Inland Revenue authorities. In view of certain High Court decisions, it was decided not to contest the demand. In recent years the Institute has maintained classification as a charity for income tax purposes. The situation may be somewhat serious so far as a large proportion of the revenue from investments in the Foundation Fund are concerned On the other hand, however, it is anticipated that when the agreement has been completed, members will be enabled to claim allowance in respect of membership subscriptions. Mr. T. Fletcher Robinson, who has acted as Hon Treasurer since 1915, recently resigned owing to advancing years, and health considerations, and Mr. Walter W L. Lishman has kindly undertaken the duties of the office. The Council desire to place on record their warm appreciation of the services of Mr. Robinson which have been associated with a successful policy of careful upbuilding of the Institute's financial resources.

Annual and Other Meetings

In connection with the last Annual General Meeting, a departure was made by the holding of the event in a centre other than that of Headquarters. Bradford was selected, and the change was regarded as sufficiently satisfactory to warrant continuance of the policy; Bolton being selected for the current year. It is now customary for the contribution of the Mather Lecture of the Institute to be in conjunction with the Annual Meeting.

The Autumn Conference was held during October in London and proved highly successful. Excellent facilities and generous hospitality were afforded and greatly appreciated. Accommodation for the reading of papers was kindly provided at the Imperial Institute, where visitors were also enabled to inspect the various departments. Messrs. Selfridge & Co. Ltd. kindly entertained the company to luncheon and afterwards conducted parties through the sections of their great store in Oxford Street. The Clothworkers' Company, as on several previous occasions of similar character, held an Evening Reception for Institute members and ladies, followed by a musical entertainment. The gathering was most enjoyable and provided an excellent opportunity for fraternisation on the part of visitors from different centres of the textile industry. A visit to the works of Messrs. Vickers (Crayford) Ltd. proved extraordinarily attractive and involved the firm named in special arrangements owing to the large number in attendance. The President of the Institute (Lieut.-Col. B. Palin Dobson) attended the Conference proceedings and the Council gratefully acknowledges his helpful services.

In connection with the office of President, a valuable gift has been made by Mr. F. W. Barwick, Chairman of the Selection Committee. The gift is in the form of a presidential badge. In gold and enamel, this insignia of office is an exquisite production and provides a highly desirable possession for use on the part of the Institute's principal officer on important occasions.

Institute Diplomas

The scheme of professional qualification of members of the Institute has continued to command an increasing measure of appreciation and recognition. Experience has fully justified the policy of the Selection Committee in framing conditions gradually from the commencement of operation of the scheme. The regulations governing awards of Associateship and Fellowship, issued in the latter part of 1927, have so far proved most effective and, with the exception of possible revision in minor details, have come to be regarded as fairly permanent. The Institute's examination of applicants of approved attainment in qualification for the Associateship is now well established and is conducted twice each year—June and December. At the last examination in December

last, there were 12 candidates—the largest number recorded for a single examination. For the year, 19 candidates sat and ten of this number passed. Applications totalled 52 in 1929 (41 Associateship and 11 Fellowship) against 48 (29 and 19 respectively) for the previous year, bringing the number of applications since the inauguration of the scheme in 1925 to 514 (284 and 230). An interesting and encouraging feature in regard to the examination has been the frequency with which candidates have presented themselves for re-examination. The Selection Committee has a big task in hand and the work is carried on with marked enthusiasm.

Journal of the Textile Institute

Though, in 1928, efforts were made to improve the financial position of the *Journal*, the full effect of the measures adopted was not felt immediately. The position in 1929 was abnormal from the point of view of comparison with previous years because of a change of policy in respect of the Proceedings and Abstracts Sections of the *Journal*; the amount of matter published and the financial result are not, therefore, strictly comparable with 1927 and 1928. The policies referred to may be briefly outlined with advantage. It was decided to publish reports of all Section meetings as soon as possible after the event and subsequently to consider papers delivered to such meetings with a view to their publication in full. Lecturers being informed in advance of this procedure have every opportunity of submitting manuscripts for the consideration of the Committee. The Abstracts Section has been almost completely changed. It is now single column 9-pt. type, whereas previously it was double column 8-pt. This change was due to an arrangement entered into with the British Cotton Industry Research Association and, later, with the British Research Association for Woollen and Worsted Industries under which the summaries of current literature produced by these Associations were printed (instead of duplicated) by the Institute's printers, thus rendering the type available for use in the *Journal*. A marked increase in requests for the loan of "original sources" may be taken as evidence that this change has been appreciated.

The total production for 1929 was as follows—Proceedings, 192 pages; Transactions, 410 pages; Abstracts, 692 pages; and Advertisements, 304 pages. The Proceedings Section contained the Mather Lecture delivered by H. T. Tizard, of the Department of Scientific and Industrial Research, at Bradford. The Cotton Yarn Association having been wound up, the *Journal* no longer constitutes its official publishing medium. A number of individuals and organisations, still far too few in view of the extreme value of this service, are now securing a supply of abstracts items mounted on cards. Such an index is being built up at the Institute and its worth for reference purposes has been amply demonstrated. The Publications Committee, in the last Annual Report, drew attention to the fact that the whole duties in connection with the *Journal*, including the advertising, as well as the normal editorial duties, had been allocated to the present Editor. This policy had been most successful. In spite of the extraordinary industrial depression, the revenue from advertising during the past year has exceeded that obtained during any single year since the publication of the *Journal* The financial position of the *Journal* has, as a result, become very satisfactory. The quality of the *Journal* and the standard of its contributions continue to justify its position amongst the scientific journals of the country.

Annual Competitions: Woven Fabrics and Yarns

The annual competitions yielded a highly satisfactory number of exhibits, many of which were of distinctly superior merit. Notwithstanding somewhat drastic revision of the requirements in relation to the principal competition, with considerable reduction of the number of specimens demanded, there was not a correspondingly substantial increase in the number of entries. In other competitions, however, the numbers of competitors increased greatly. The Headquarters display of the exhibits has previously been limited to the day of prize presentation. On the last occasion, however, the exhibits were on view for an additional day, when admission was general The experiment was successful from the point of view of number of visitors and the arrangement for extended period of display is to be continued this year. By the death of Mr. A. E. G. Brookes, the Competitions Committee were deprived of valuable assistance in relation to the Institute's annual collection of specimens of current textile fabrics. Miss Dust and Mr. J. M. Essam, of the Manchester College of Technology, kindly undertook to engage in the work and the collection for 1929–30 has been most favourably received. The period (three years) of contribution of prize money by Messrs. R. Greg & Co. (South Reddish) expired at the end of 1928, and effort by the Chairman of the Competitions Committee to secure a further contribution from elsewhere resulted in a kind donation of £25 on the part of Mr. Frederick Lye, of Rochdale, a generous supporter of the Institute movement over many years past. It is hoped that further assistance from other supporters may be forthcoming at an early date.

Invested Funds

The total donations to the Foundation Fund of the Institute at the end of 1929 reached £19,020 11s. 6d. This amount includes £289 9s. 5d. profit on conversion of War Bonds. The amount also includes £861 9s. 6d. from the Institute Diplomas Account, £250 from relinquishment of former London office premises, £2,500 Crompton Memorial Fund (nominal value), and £5,000 donation from the Cotton Reconstruction Board and the Trustees of the Cotton Trade War Memorial Fund. The whole amount is invested with the exception of a small balance at bank of £4 16s. 6d. The interest from the Crompton Fund is applied to the Competitions Scheme, that from the London office tenancy surplus to the London Section, and that from the contribution from the Cotton Reconstruction Board and Cotton Trade War Memorial Fund is reserved for a special scholarship scheme at present being formulated.

Inquiries, and Employment Register

The service of the Institute with reference to inquiries not only from members but from various organisations and authorities, continues to expand, and replies forwarded are reported upon monthly to the appropriate Committee. Many officers and members have assisted materially in providing required information and a growing measure of exchange of valuable information is taking place among members by reason of the facilities available. The Employment Register is frequently used and particulars of qualifications and experience of candidates for vacant posts are promptly provided to employers seeking information as to services on offer. In this connection, there has been further evidence of growing demand for the services of individuals possessing diplomas of the Institute.

Institute Rooms and Library

The rearrangement of the headquarters premises with a view to improvement of facilities for visiting members has proved increasingly effective. The library is now mainly contained in the Members' Room, which offers good accommodation for reading and writing, whilst refreshments may be obtained. For some years past, the books possessed by the Institute could be regarded as forming the nucleus of a textile library. The number of volumes available was steadily increasing, but not only financial but also accommodation difficulty prevented progress. The formation of a Library Committee, however, resulted in proposals which the Council readily adopted. It was decided to accept a scheme for housing the existing books in the Members' Room. Bookcases, built up on the unit system, and therefore capable of future extension were acquired at a cost of £250. A printed catalogue was prepared and is now available. The past year has witnessed a marked increase in the use of the Library for reference purposes and the facilities for borrowing of books have been well appreciated.

Council and Committee Meetings

The following is the record of meetings held during the year (1st January to 31st December 1929)—Council, 11; Selection, 11; Publications, 11; Finance, 13; Propaganda, 5; Competitions, 3; Library, 5; Research, Testing, and Inventions Advisory, 3; Lancashire Section, 1; London Section, 8; Irish Section, 2; Yorkshire Section, 5; Total 78; as against 85 in the previous year. In addition to the foregoing, five sub-committees met for the consideration of special matters.

Section Meetings and Lectures

Seven meetings of the Lancashire Section, and four joint meetings; two meetings of Yorkshire Section, and five joint meetings; nine of the London Section, and one visit; two of the Irish Section; and three of the Scottish Section were held during 1929, at which papers were read and discussed.

Membership

The membership at the end of 1929—to be carried forward to 1930—was made up as follows—Honorary Members, 7; Life Members, 36; Members, 1,421; Junior Members, 105; Non-subscribing Members, 1; total, 1,570.

The totals for the foundation year (1910) and the years 1921 to 1929 were—1910, 233; 1921, 904; 1922, 994; 1923, 1,039; 1924, 1,083; 1925, 1,275; 1926, 1,395; 1927, 1,449; 1928, 1,498.

The Council lament the loss by death during 1929 of H. N. Bickerton (Siddington); A. E. G. Brookes (Marple); C. Clegg (Manchester); L. Dubois (Switzerland); A. Hoegger (Manchester); W. H. Horrocks (Holland); F. Kershaw (Bolton); C. E. Murphy (Halifax); Wm. Peers (Bury); J. T. Randles (Birmingham); C. F. Townsend (London); J. G. Watson (Dunfermline); T. R. Wharton (Manchester).

In the early part of the present year, also, the Institute has lost several prominent members, full reference to which has already been made in the *Journal*. The names include Sir Frank Warner (London), Past-President; W. R. Cooper (London); W. Eastwood (Liverpool); A. G. Lupton (Leeds); and G. H. Stafford (Hyde).

HON. TREASURER'S REPORT

This report was read by Mr. T. Fletcher Robinson, who said it was the 16th report he had presented and the last, as he had now relinquished his office. He wished to testify to the great satisfaction felt both by the Council and by himself at the appointment of Mr. W. W. L. Lishman as his successor.

I have the pleasure to present, as Hon. Treasurer, my 16th and last Annual Report and the Institute's Accounts and Balance Sheet, for the year ending 31st December 1929, that have been certified as correct by the Auditors.

FOUNDATION FUND—This fund had a total capital on the 31st December 1929, of £19,403 2s. 0d. as against £19,317 12s. 0d. the previous year, of which £19,218 4s. 0d. is invested and £184 18s. 0d. is in hand awaiting to be invested. The invested funds include amounts allocated to special purposes, viz.—

	£	s.	d.
Grant from Cotton Reconstruction Board for Scholarships ...	5,000	0	0
London Section Reserve Account	250	0	0
Life Membership Reserve Fund	277	0	0
Diploma Account	861	9	6

The total interest from investments was £868 15s. 2d., the interest being allocated as follows—

	£	s.	d.
To Perpetual and Life Membership Subscriptions ...	52	5	10
,, London Section	12	0	0
,, Scholarship Scheme	243	10	0
,, Crompton Fund	50	0	0
,, "Mather" Lecturer	25	0	0
,, *Journal* Account	220	6	3
,, Revenue Account	265	13	1
Total	£868	15	2

"JOURNAL" ACCOUNT—The finances have improved as shown by the amount needed to be transferred from the Foundation Fund being reduced from £468 6s. 6d. in 1928, to £220 6s 3d. in 1929. The accounts now presented include 1928 figures and exclude certain 1929 amounts; had these been adjusted the actual 1929 account would have shown a credit balance of £42 12s. 7d , and no transfer to *Journal* Account from the Foundation Fund would have been needed Printing, Reprints, etc., have cost £2,970 9s. 10d. against £2,407 14s 6d. in 1928 Salaries and wages £684 19s. 8d. against £667 14s. 8d. The grants from Cotton and Linen Research Associations have been £150 and £100 respectively, the same as the previous year. Advertisements have increased by £408 19s. 7d. The year's result being improved by £441 16s. 8d. upon the year 1928.

REVENUE ACCOUNT—Members' subscriptions have been £3,112 10s. 2d. from 1,405 members, being £138 14s 5d more than 1928 from 1,324 members. These receipts from members' subscriptions were credited in the usual proportions—£2,023 2s. 8d. to Revenue Account, and £1,089 7s. 6d (35%) to *Journal* Account Salaries and wages were £905 5s. 5d. against £898 3s. 4d. in 1928 Offices, Canteen, etc , £43 15s. 5d. less; meeting expenses £160 18s. 8d. less; postages £8 6s. 6d. more; Autumn Conference cost £23 16s. 0d.; Library Account, £35 9s. 2d. against £30 0s. 6d. The five Sections spent £347 18s. 7d. against £524 10s. 1d. in 1928.

There has been the usual transfer of £20 from the Crompton Fund towards the cost of its administration, and the balance on Diploma Account of £117 19s 4d. has been credited to Revenue Account. The Credit Balance on Revenue Acccunt for 1929 is £52 19s. 6d., which, by the transfer of the balance on Foundation Fund Account increases the Credit Balance to £289 6s. 8d. with which to commence the new year.

Expenditure comparisons show that Rent, Rates, Heating, Lighting, and Cleaning have cost—1918, £219; 1926, £313; 1929, £320 19s. 9d. Salaries and Wages of Staff (including *Journal*) at Headquarters have been—1918, £453; 1924, £1,248; 1928, £1,540; 1929, £1,615 5s. 1d.

Arrears of subscriptions written off this time are £18 18s. 0d. against £87 3s. 0d. in 1928, leaving the arrears on 31st December 1929, £155 7s. 0d. as against £105 2s. 0d. in 1928.

Receipts from members' subscriptions have been—Year 1918, £851; 1919, £1,394; 1922, £1,774; 1924, £2,266; 1926, £2,489; 1927, £2,790; 1928, £2,973; 1929, £3,112 10s. 2d., being an increase for the year of £140.

CROMPTON MEMORIAL PRIZE FUND—This year printing and stationery has cost £64 18s. 0d. against £35 in 1928. The cost of specimens, £92 17s. 4d.,, represents the cost for two years. Prizes were £123 9s. 8d. against £153 4s. 0d. Subscriptions for albums were £141 3s. 0d., being £2 2s. 0d. more than 1928. The Council have to thank Mr. Frederick Lye for his generous donation of £25 for yarn prizes. The expenditure

has been £56 more than the receipts, still leaving a balance in hand of £112 9s. 7d., against £169 4s. 11d. the previous year.

DIPLOMA ACCOUNT—The Diploma Fees from 10 Fellows and 16 Associates have been £147 1s. 0d. as against £179 8s. 2d. in 1928, from 13 Fellows and 23 Associates; and in 1927, £440 from 38 Fellows and 56 Associates; and in 1926, £979 from 98 Fellows and 83 Associates. The credit balance of £117 19s. 4d. has been transferred to the Revenue Account.

COTTON RECONSTRUCTION BOARD SCHOLARSHIP ACCOUNT—This fund of £5,000 has now in hand £313 10s. 0d. accumulated dividends.

SCHEDULE OF INVESTMENTS—

	£	s.	d.
Cotton Reconstruction Board Scholarship Scheme, Invested value ...	4,870	0	0
Diploma Account, invested value ...	861	9	6
London Section, invested value ...	240	0	0
Crompton Fund ...	2,500	0	0
Life Membership Account ...	105	0	0
Perpetual Membership Account ...	97	10	0
Foundation Fund ...	10,544	4	6
	£19,218	4	0
Awaiting investment ...	184	18	0
	£19,403	2	0

The membership of the Institute on 31st December 1929, was 1,570, against 1,498 for 1928, and in addition 238 *Journal* subscribers.

The net increase in members has been—1925, 192; 1926, 120; 1927, 54; 1928, 49; 1929, 72 more.

The particulars of the chief differences in 1929, as shown by the following figures, will help to the clearer understanding of the position—

GAINS		£	s.	d.	£	s.	d.
Advertisements for *Journal* ...		356	3	4			
Journal Subscriptions ...		52	16	3			
General Members' Subscriptions ...		138	14	5			
Meeting Expenses ...	*less*	167	18	8			
London Expenses ...	*less*	92	16	3			
Yorkshire Expenses ...	*less*	81	5	5			
Cleaning, Canteen, etc. ...	*less*	63	17	6			
					953	11	10
EXTRA COSTS							
Salaries and Wages ...		71	7	1			
Furniture Depreciation ...		21	18	5			
Diploma Account, *less* available for transfer ...		37	3	8			
Autumn Conference ...		22	17	2			
Library ...		5	3	11			
Journal Printing ...		86	14	10			
Journal Postages, etc. ...		45	14	9			
Journal Stationery, etc. ...		54	18	9			
					345	18	7

The final result shows that the financial position for the year 1929 is very satisfactory, there being a credit balance on the 31st December 1929, of £289 6s. 8d. after having paid off the deficit of 1928 of £223 13s. 1d. This represents an increase in the receipts more than the expenditure of £512 19s. 9d. for the year 1929

In laying down my duties as Hon. Treasurer, after having held the position since 1914, I am pleased to report the continued increase of members during that period (from 240 in 1914 to 1,570 in 1929), and that the year has also been very satisfactory in its finances, so that I am able to report this considerable sum of £289 6s. 8d. in hand with which to commence the "coming of age" year of the Institute.

I congratulate the Institute in having secured the services of Mr. Lishman as my successor. Knowing as I do his competence and experience, I am sure that the finances of the Institute will be in safe hands.

I conclude with the expression of my great appreciation of the help I have received from the members and from the staff. My work has been a labour of love, and my life has been enriched by the kindness and good fellowship of you all, and I shall always cherish with affection the many friendships I have been privileged to form. We are all justly proud of the splendid work of the Institute and its ever-widening usefulness, and I pray that its good work may continue to increase to the advantage of the textile industry generally.

T. FLETCHER ROBINSON

Hon. Treasurer

Dr. The Textile Institute—Balance Sheet as at 31st December 1929 Cr.

1928 £ s. d.	LIABILITIES	£ s. d.	£ s. d.
192 2 0	Subscriptions paid in advance ...		140 10 0
	Life Membership Subscriptions Account—		
	Balance, as on 31st Dec. 1928 ...	68 6 5	
68 6 5	*Less* 10% transferred to Revenue Account	8 10 10	59 15 7
	Sundry Reserves, *viz.*—		
193 0 0	Life Membership Reserve Account	277 0 0	
97 10 0	Perpetual Membership „ ...	97 10 0	
2500 0 0	Crompton Prize Fund	2500 0 0	
10415 12 6	Foundation Fund	10417 2 6	
5000 0 0	Do. Cotton Reconstruction Board Grant	5000 0 0	
861 9 6	Do. Diplomas Account ...	861 9 6	
250 0 0	Do. London Section Reserve Account	250 0 0	19403 2 0
169 4 11½	Competitions Scheme—Income and Expenditure Account Balance		112 9 7½
70 0 0	Scholarship Scheme—Reserve Account		313 10 0
75 0 0	*Journal* Account—Reserve to 1930, Subscription from B.C.I.R.A. for period unexpired		75 0 0
417 10 4	Sundry Creditors as per list ...		301 1 6
143 1 1	Bank Overdraft—General Account		22 11 7
	Revenue Account—Excess Income over Expenditure for Year ...	289 6 8	
– – –	*Less* Debit Balance on 31st Dec. 1928	236 19 10½	52 6 9½
£20452 16 9½			£20480 7 1

1928 £ s. d.	ASSETS	£ s. d.	£ s. d.
	Cash at Bank—		
11 8 0	Foundation Fund Account ...		4 16 6
5 9	Cash in hand		12 17 1
	Sundry Debtors—		
	Journal Account—		
	Outstanding Advts. ...	326 8 3	
252 2 1	Outstanding Reprints ...	59 12 5	386 0 8
	Furniture, Fittings, and Library Account—		
	Balance as on 31st Dec. 1928...	462 5 10	
	Additions during Year ...	268 0 10	
		730 6 8	
462 5 10	*Less* Depreciation	97 9 5	632 17 3
	London Furniture Account—		
	Balance as on 31st Dec. 1928...	43 15 0	
	Additions during Year ...	4 1 6	
		47 16 6	
43 15 0	*Less* Depreciation	5 19 6	41 17 0
9 10 0	Gas and Electricity Deposits ...		9 10 0
	Investment Account (see Schedule)		
	Foundation Fund ...	16515 14 0	
	Crompton Prize Fund... ...	2500 0 0	
	Life Membership Account ...	105 0 0	
19218 4 0	Perpetual Membership Account ...	97 10 0	19218 4 0
218 6 3	Office and Rooms Alterations Account—Balance		174 4 7
236 19 10½	Revenue Account		– – –
£20452 16 9½			£20480 7 1

AUDITORS' REPORT TO MEMBERS

We report to the members that we have examined the above Balance Sheet together with the books and vouchers of the Institute, and that we have obtained all the information and explanations we have required.

We further report that in our opinion the Balance Sheet is properly drawn up so as to exhibit a true and correct view of the Institute's affairs according to the best of our information, and the explanations given to us, and as shown by the books of the Institute.

W. W. L. LISHMAN *Hon. Treasurer.*
FRANK NASMITH *Chairman of Council.*

26th February 1930
37 York Street Manchester.

(*Signed*) ARTHUR E. PIGGOTT, SON & SOUTHWORTH
Incorporated Accountants, Auditors.

Dr. The Textile Institute—Revenue Account for the Year ended 31st December 1929 Cr.

EXPENDITURE

1928 £ s. d.	EXPENDITURE	£ s. d.	£ s. d.
	To Rent and Rates—Manchester ...	228 7 10	
162 10 4	*Less* to *Journal* Account ...	76 2 7	152 5 3
	„ Salaries	1259 18 0	
625 0 0	*Less* to *Journal* Account ...	609 18 0	650 0 0
50 0 0	Salary—Proportion to London Section		— — —
	„ Wages	355 7 1	
223 3 4	*Less* to *Journal* Account ...	100 1 8	255 5 5
	„ Heating, Lighting and Cleaning...	92 11 11	
74 9 4	*Less* to *Journal* Account ...	30 17 4	61 14 7
123 18 1	„ Offices, Canteen, and General Expenses, etc.		80 2 8
205 9 4	„ Meetings Expenses	37 10 8	
20 12 11	„ Travelling Expenses	20 18 7	58 9 3
116 7 7	„ Postages, Telegrams, and Telephones		124 14 1
156 4 4	„ General Printing and Stationery		163 9 10
6 7 10	„ Insurances		5 9 6
15 17 6	„ Audit and Accountancy Charges		21 3 0
5 10 0	„ Subscriptions to Institutions ...		5 5 0
18 10	„ Autumn Conference—Expenses *Less* Receipts		23 16 0
30 5 3	„ Library Account		35 9 2
	„ Section Expenses—		
370 17 4	London	278 1 1	
30 0 6	Lancashire	27 17 9	
111 13 6	Yorkshire	30 8 1	
	Scotland	5 10 2	
11 18 9	Ireland	6 1 6	347 18 7
44 1 8	„ Office Alterations—Amount written off		44 1 8
81 10 6	„ Depreciation on Furniture ...		103 8 11
— — —	„ Bank Charges, *less* Interest ...		1 11 2
— — —	„ Exhibition Expenses, *less* Receipts		3 4 4
2466 16 11			2137 8 5
— — —	„ Excess Income over Expenditure		289 6 8
£2466 16 11			£2426 15 1

INCOME

1928 £ s. d.	INCOME	£ s. d.	£ s. d.
	By Membership Subscriptions—		
	1247 Members at £2 2s. ...	2618 14 0	
	30 „ £1 1s. (half-year)	31 10 0	
	117 Junior Members at £1 1s.	122 17 0	
	11 „ „ at 10s. 6d. (half-year)	5 15 6	
	Life Members—10% of Balance	8 10 10	
	Subscriptions in advance as per Balance Sheet, 31st Dec. 1928	192 2 0	
	Subscriptions in Arrear paid during 1929	57 15 0	
	Interest from Perpetual Membership, Life Membership, and Diploma Account Investments	52 5 10	
	Special Subscription — The Weavers' Company	21 0 0	
	Donation—Whipp Bros. & Co.	2 0 0	
		3112 10 2	
1932 19 6	*Less* amount transferred to *Journal* Account	1089 7 6	2023 2 8
20 0 0	„ Crompton Fund Administration Expenses		20 0 0
155 3 0	„ Diplomas Account — Amount transferred		117 19 4
128 17 4	„ Foundation Fund—Income from Investments Account—Amount transferred		265 13 1
17 6	„ Bank Interest, *less* Charges ...		— — —
5 6 6	„ Empire Textile Conference Reports		— — —
2243 3 10			2426 15 1
223 13 1	„ Excess Expenditure over Income		— — —
£2466 16 11			£2426 15 1

TOTAL ARREARS at 31st Dec. 1929	£174 5 0
ARREARS WRITTEN OFF ...	18 18 0
Total Arrears Current...	155 7 0

W. W. L. LISHMAN *Hon. Treasurer.*
FRANK NASMITH *Chairman of Council.*

Audited and found correct,
28th February 1930 ARTHUR E. PIGGOTT, SON & SOUTHWORTH
37 York Street Manchester. *Incorporated Accountants, Auditors.*

Dr. The Textile Institute—Crompton Prize Fund Income and Expenditure Account for Year ended 31st December 1929 Cr.

1928 £ s. d.	EXPENDITURE	£ s. d.
35 3 0	To Printing and Stationery	64 18 0
7 8 9	,, Purchase of Specimens	92 17 4
	,, Mounting of Specimens	8 2 6
153 4 0	,, Prize Awards and Expenses	123 9 8
10 18 2	,, Postages, Carriage, etc.	4 14 10
20 0 0	,, Administration Expenses	20 0 0
226 13 11		314 2 4
169 4 11½	,, Balance carried forward	112 9 7½
£395 18 10½		£426 11 11½

1928 £ s. d.	INCOME	£ s. d.
142 11 10½	By Balance brought forward	169 4 11½
139 1 0	,, Albums Subscriptions	141 3 0
4 6 0	,, Competition Entrance Fees	5 4 0
50 0 0	,, Dividend on £1000 5% War Stock ...	50 0 0
36 0 0	,, Dividend on £1125 4% L.M.S. Railway Stock	36 0 0
24 0 0	,, Prize Money (Yarns)—Fredk. Lye, Esq. ...	25 0 0
£395 18 10½		£426 11 11½

Dr. The Textile Institute—Foundation Fund Income from Investment Account for Year ended 31st December 1929 Cr.

1929	EXPENDITURE	£ s. d.
April 12	To Mather Lecture...	25 0 0
Dec. 31	,, Transfer to *Journal* Account	220 6 3
,, 31	.. Transfer to Revenue Account	265 13 1
		£510 19 4

1929	INCOME	£ s. d.
Feb. 1	By Dividend £1242 10s. 4% Consolidated Stock *less* Tax	£19 17 8
May 1	,, ,, £1000 4% Funding Loan 1960-1990 *less* Tax	16 0 0
June 1	,, ,, £8784 3s. 2d. 5% War Stock 1929-1947	219 12 0
Aug. 1	,, ,, £1242 10s. 4% Consolidated Stock *less* Tax	19 17 8
Nov. 1	,, ,, £1000 4% Funding Loan 1960-1990 *less* Tax	16 0 0
Dec. 1	,, ,, £8784 3s. 2d. 5% War Stock 1929-1947	219 12 0
		£510 19 4

Dr. The Textile Institute—Diplomas Account for Year ended 31st December 1929 Cr.

1928 £ s. d.	EXPENDITURE	£ s. d.
21 17 3	To Sundry Expenses, Printing, and Meetings ...	15 8 11
24 9 8	.. Expenses *re* Examinations	25 17 9
155 3 0	,, Transfer to Revenue Account	117 19 4
£201 9 11		£159 6 0

1928 £ s. d.	INCOME	£ s. d.
9 11 3	By Balance brought forward	— — —
179 8 2	,, Diploma Fees	147 1 0
10 10 0	,, Examination Fees	10 10 0
2 0 6	,, Sale of Regulations	1 15 0
£201 9 11		£159 6 0

W. W. L. LISHMAN *Hon. Treasurer.*
FRANK NASMITH *Chairman of Council.*

Audited and found correct,
26th February 1930 ARTHUR E. PIGGOTT, SON & SOUTHWORTH
37 York Street Manchester. *Incorporated Accountants, Auditors*

The Textile Institute—Journal Account for the Year ended 31st December 1929

Dr. — EXPENDITURE

1928 £	s.	d.		£	s.	d.
2331	9	9	To Printing, Reprints, and Postages (Distribution)	2906	5	5
76	4	9	„ Literary Contributions and Abstracts ...	64	4	5
450	0	0	„ Salaries	609	18	0
217	14	8	„ Wages (*less* £25 Ring Yarn Association) ...	75	1	8
19	5	4	„ Postages, Telegrams and Telephones... ...	65	0	1
36	16	2	„ Stationery, Binding, and *Journals* purchased	91	14	11
73	13	9	„ Advertisement Commission	56	2	0
11	5	9	„ Travelling Expenses	7	5	0
81	5	2	„ Rent and Rates (Proportion)	76	2	7
37	4	8	„ Heating, Lighting, and Cleaning (Proportion)	30	17	4
75	0	0	„ Reserve—Subscription from B.C.I.R.A. carried forward	75	0	0
£3410	0	0		£4057	11	5
241	0	9	To Advertisement Accounts Outstanding ...	326	8	3
9	16	4	„ Reprints Accounts Outstanding	59	12	5

Cr. — INCOME

1928 £	s.	d.		£	s.	d.	£	s.	d.
125	0	0	By Reserve—Subscription from B.C.I.R.A., brought forward				75	0	0
			„ Grants—						
150	0	0	British Cotton Industry Research Association... ...	150	0	0			
100	0	0	Linen Industry Research Association	100	0	0	250	0	0
10	10	0	„ Subscription from Clothworkers' Company ...				10	10	0
1340	7	1	„ Advertisements and *Journal* Subscriptions ...				1749	6	8
175	0	2	„ Reprints				663	1	0
1040	16	3	„ Transfer from Membership Subscriptions ...				1089	7	6
468	6	6	„ Transfer from Foundation Fund				220	6	3
£3410	0	0					£4057	11	5
360	11	1	By Sundry Creditors for Printing...				232	16	2
75	0	0	„ Reserve—Subscription from B.C.I.R.A. ...				75	0	0

Schedule of Investments (at Cost or Value at original date of gift) as on 31st December 1929

Foundation Fund—

		£	s.	d.	£	s.	d.
£8784 3s 2d.	£3737 14s. 9d. 5% War Stock 1929-1947	3503	7	0			
	£4789 9s. 5d. 5% War Stock 1929-1947	4789	9	5			
	£48 16s. 3d. 5% War Stock 1929-47	49	14	1			
	£105 5s. 3d. 5% War Stock 1929-1947	106	14	0			
	£102 17s. 6d. 5% War Stock 1929-1947						
	£4870 0s. 0d. 5% War Stock 1929-1947 (Scholarship Scheme) ...	5355	0	0			
	£240 0s. 0d. 5% War Stock 1929-1947 (London Section)						
	£650 0s. 0d. 5% War Stock 1929-1947 (Diplomas)	661	9	6			
	£194 9s. 2d. 5% War Stock 1929-1947 (Diplomas)	200	0	0			
	£1000 4% Funding Loan 1960-1990	800	0	0			
	£1242 10s. 0d. 4% Consolidated Stock	1050	0	0	16515	14	0

	£	s.	d.	£	s.	d.
Brought forward				16515	14	0
Crompton Prize Fund—						
£1000 5% War Stock 1929-1947 ...	1000	0	0			
£1125 4% L.M.S. Railway Preference Stock	1500	0	0	2500	0	0
Life Membership Account						
£52 5s. 0d. 5% War Stock 1929-1947	53	14	6			
£50 5% War Stock 1929-1947 ...	51	5	6	105	0	0
Perpetual Membership Account—						
£99 1s. 6d. 5% War Stock 1929-1947				97	10	0
				£19218	4	0

W. W. L. LISHMAN *Hon. Treasurer.*
FRANK NASMITH *Chairman of Council.*

Audited and found correct,
26th February 1930 37 York Street Manchester. ARTHUR E. PIGGOTT, SON & SOUTHWORTH *Incorporated Accountants, Auditors.*

The adoption of this report, together with the Auditor's Report, Balance Sheet, and Accounts for 1929, was moved by Mr. W. Frost, and seconded by Col. F. R. McConnel. Both speakers paid tribute to the excellent work that had been done by the retiring Hon. Treasurer and congratulated him upon the satisfactory state in which he left the Institute's finances.

ELECTION OF PRESIDENT

The Chairman, proposing the re-election of Colonel Palin Dobson as President, stated that only those who had been members of the Council during the past past twelve months knew the really active interest Colonel Dobson had taken in the work of the Institute. On many occasions he had taken the chair and on other occasions he had attended the Conferences of other Associations and Federations, and at the Barcelona Conference he conferred an honour on the Textile Institute by wearing the President's badge of office. The organisation of the celebrations in connection with the coming-of-age of the Institute made it essential that they should have such an active personality in the Presidential chair as Colonel Palin Dobson. It was a pleasure to propose his re-election because he remembered that 35 years ago he sat in that very room at which Colonel Dobson's father gave an address and his (the speaker's father) was in the chair.

Mr. C. S. Ickringill seconded, and said that as a member of the Institute from outside Lancashire he was glad that Colonel Dobson was again prepared to accept the office. He would like to supplement the Chairman's remarks regarding the President's activities outside the Council. He had given every possible support in London and in Yorkshire and in other parts of the country. At a time like the present when the Institute had such a great work before it, it was essential to have activity from the top to bottom.

Lieut.-Col. Dobson, in reply, said—I very deeply appreciate the honour that the Textile Institute has done to me in again electing me President for the coming year. It is an additional pleasure that this year my election takes place in my native town of Bolton, a town in which an ancestor of mine, Mr. Isaac Dobson, came to live just over 140 years ago, at the same time founding the firm of textile machinists which still bears the name of Dobson, and of which I am Director.

At my election to the office of President in April of last year, I spoke of the depression at the time in the great textile industry, embracing all its branches, and hoped that before my first year of office ended the industry would show signs of improvement in trade. Unfortunately this improvement has not materialised, indeed, if possible, trade is much worse I think it may be said that the trade itself, in all its branches is doing what it can, and with certain success, to effect such economies and increases in efficiency as will tend to lower the costs of production and so be in the best position present circumstances permit to place its goods on the markets of the world as cheaply as possible. The textile machinists are in the same depressed condition as the spinners and weavers. The causes of this trade depression are not far to seek.

In the first place the weight of taxation which this country has to bear is out of all proportion to those of any of our competitive countries. All increased factory legislation puts increases on the cost of production in the industry and is a further drain on the unfortunate goose which has to lay the golden eggs. Nationally we are burning the candle at both ends. Considering the taxation per head of the population we are burning it over twice as fast as Germany, nearly three times as fast as France, over four times as fast as Italy. The result is a foreseen conclusion unless steps are taken to remedy matters.

For years we have been living on our capital and our credit has suffered. Like fools we allow all our neighbours, who have a less burden of taxation to bear and who have a protective tariff wall round their country, to dump their surplus stuff in Great Britain at prices against which English manufacturers cannot

hope to compete. We do this, and some of us hypocritically talk about the blessing of free imports which enables one to buy a German, Japanese, or French pocket handkerchief cheaper than an English one, whilst thousands of English spinners and weavers are walking the streets unemployed, and living on the dole which comes from the injured industry. I am not talking politically. I deplored in my lecture given to the Royal Technical College, Salford, on the 15th January of this year, that an economic question has been made a political one. In a New Year's message to the *Textile Mercury* I expressed the same opinion, and take this opportunity to plead once more that the question of safeguarding of industry is one not of politics but of economics. It is of supreme importance to British industry and it is a factor which, if not adopted at once, will be unable to save that industry from practical extermination, and reduce the country to the condition of the Swiss village mentioned by Mark Twain in which the inhabitants "eked out a precarious existence by taking in each other's washing."

There are most encouraging signs that that most obstinate disease "Cobdenitis" is being slowly stamped out. Of course, there are incurables, and unfortunately some of the incurables control the destiny of our country. We can only pity them for worshipping at the shrine of a fallacy, in happy ignorance of the fact that Europe of 1930 is quite unlike the Europe of fifty years ago. We are no longer the workshop of the world and there has been the biggest of all wars, costing us financially in debt a mint of money, which we shall not pay off in the next two generations, and it is industry which will have to pay off this debt. There is an old saying that "you cannot have your cake and eat it" The Government apparently thinks otherwise. Let us hope that they will realise their mistake before it is too late. Industry shouldering this excessive financial burden is beginning to stagger, every stone thrown by foreigners in the shape of free imports, adds to the difficulty of progress of the tottering figure. It is the duty of everybody to insist that the Government should lighten the burden not add to it, and to render harmless the outside attacks by safeguarding industry. I speak of 'Safeguarding' only, as I consider that this is hardly a controversial question, or at any rate should not be. Therefore, I do not speak of the question of protective tariffs, as this may be open to reasonable argument. The state of affairs may appear hopeless, but there is no reason to give up hope—the remedy is in our own hands. Rigorous economy is the first essential, particularly in the unproductive Government expenditure. We must put our foot down on financing utopian social service dues which we cannot afford, and we must endeavour to place a Government in power who will pledge themselves to economy. Secondly we must place in power those who will protect the fruits of industry. Thirdly we must get the country as a whole to recognise the fact that industry is the backbone of the country—by industry it lives—by industry it pays its way—without industry the country is doomed. The budget this year does nothing to help industry. The income tax increase is the utilisation of money which should eventually go back into industry, for unproductive and expensive social services. It is all very well to talk about a deficit—it is the business of the Government to effect economy, and the first economy should be in cutting their coat according to the cloth. The only thing to do is for business men to try and instil into the country the fact that Rationalisation of Industry, Bank help for industry, etc., are only palliatives, and it is only by means of safeguarding our industries that we can look forward to a period of prosperity. Let us approach this question as individualists, in a spirit of reason, let us consider it from the point of view of economics and let us banish this senile political hypocrisy. Let us lay the ghost of Cobden whose Free Trade theory will in a very short time be so discredited as to make future generations wonder at the state of mentality of the present generation, who permitted themselves to suffer such trade depression in order to uphold an obsolete and erroneous creed. If the recent Cotton Fair had been held in Hong Kong, Montreal, Cape Town, Melbourne,

or other important places within the British Empire, a great impetus would have been given to trade within our Empire. It is impossible for industries to exhibit to the extent that is necessary, whilst undergoing the process of being taxed out of existence, but something could be done, if the Government would spend some of the money they are wasting on social services for the benefit of industry. What I suggest is this. Charter our biggest liner, fix her up as a semi-permanent exhibition in machinery, cotton, woollen and staple fibre yarns, and piece goods, and indeed all English industrial productions where export trade is essential. Send her for a cruise for twelve months, or more, to visit every port in the Empire, then foreign ports. Charge a small fee for entrance, and Advertise, Advertise, Advertise! Have competent salesmen on board who could book orders, with if possible, free or at any rate priority wireless accommodation placed at the disposal of the ship's commercial representatives. If the Government is serious in its desire to help industry, it would recognise and finance such a floating exhibition.

I again thank you for the honour you have done me in re-electing me to the position of President of the Textile Institute. I have found the Institute of great help commercially, and trust that all members will use and support the Institute to the best of their power, both by obtaining new members and utilising the facilities provided by the Institute for increasing the efficiency of the textile trades.

Mr. H. P. Greg said he thought the President's address might convey to the world that the Textile Institute or the textile trade held a certain view with regard to safeguarding. He merely rose to say that at any rate he did not hold the President's view, and felt that he must make it perfectly clear that this country lived by exports. If we could not stand the racket on our own doorstep we were not likely to stand it elsewhere, and unless we import we cannot export. He did not want to discuss the matter, but he wanted to make it clear that the President did not state the views of the Institute.

The President said that these questions ought to be studied from a business point of view, but he was expressing his own opinion.

Three nominations had been received for election to Vice-Presidency, and as these completed the vacancies, the President declared the following elected—Messrs. F. Anderson, F. Nasmith, and W. Turner.

The acting General Secretary presented the result of the ballot for the election of ten members of Council, and the President made the following declaration—*Elected*- F. W. Barwick (Manchester), J P. Beveridge (Dunfermline), W. T. Boothman (Bolton), H. Bromiley (Bolton), W. Kershaw (Manchester), T. Morley (Leicester), W. E Morton (Manchester), J. Robinson (Bradford), S. Watson (Hyde), J C. Withers (Manchester).

Appointment of Auditors--The re-appointment of Messrs. Piggott, Son and Southworth, Ltd., as auditors, was moved by Mr. W. W. L. Lishman, seconded by Mr. T Fletcher Robinson, and seconded.

PRESENTATION OF INSTITUTE'S MEDAL

Mr. Frank Nasmith, in a short introduction to the ceremony of presenting the Institute medals, said—

The award of an Institute Medal to Messrs John Crompton, William Frost, Frederic Robert McConnel, and Thomas Fletcher Robinson, is an occasion upon which some reference may be made to the circumstances under which this Medal came into being.

So far back as January 1917, at a Meeting of the Institute Council, Sir (then Mr.) Frank Warner, Chairman of Council, "raised the question of the position of the Institute in relation to various research movements and suggested that steps be taken with a view to substantial increase of Institute membership." After what is described in the minutes as "prolonged discussion" it was agreed that "the Chairman endeavour to secure a meeting with the Presidents and

Past-Presidents with a view to taking such steps as may be considered necessary to promote vastly increased membership." It is interesting to note that the inauguration of the movement which has had such far-reaching results in the development of this Institute may be definitely assigned to the late Sir Frank Warner. His services to the Institute now appear to be of a magnitude not perhaps fully realised by many of us heretofore. Sir Frank Warner's personal services, it is suggested, should be marked by the periodical award of a "Warner" medal and the tentative scheme has the warm support of the Council.

The Institute Medal

The meeting of President and Past-Presidents referred to above was held at the Carlton Hotel, London, and there were present Sir William Mather (President), Sir William Priestley (Past-President), Sir Frank Warner, and Messrs. George Garnett, George L. Craig, T. Fletcher Robinson, and Colonel McConnel. Of this meeting it may be said that from it evolved two big things, "The Institute Development Scheme" and the "Foundation Fund" to finance the scheme. The meeting did more than this: it revealed also the deep interest the then President, the late Sir William Mather, was prepared to take and did take in the whole scheme. At first, like any other project, many points were raised and side issues emerged. From the matters discussed a history of the Institute could be compiled. Possibly at the coming-of-age of the Institute, which we celebrate next year, such a history will be written, Here I will confine myself to the main theme, the Development Scheme, since the presentation of an Institute Medal really forms an integral part of that scheme. The appeal for funds, of course, went on and, though modified from the original suggestion to secure fifty donors of £1,000 each, by Sir William Mather (he offered to give and did ultimately give £1,000), it has now reached the respectable total of £10,020 11s. 6d. As offshoots of the movement the Institute now has (*a*) a Competitions Committee, administering as its chief function the income from £2,000 given by Mr. John Crompton in memory of his soldier-son Lieut. Harry Dent Crompton; (*b*) a Research Testing and Inventions Advisory Committee which is now approaching a big work in surveying the whole question of the Standardisation of Testing Textiles; (*c*) a very much developed and widely-read *Journal*; (*d*) the nucleus of a very useful Library (a catalogue is now ready); (*e*) a Royal Charter—mainly due to the generosity and driving power of our Past-President, Mr. John Emsley, but still directly traceable to the original plan of development—which constitutes

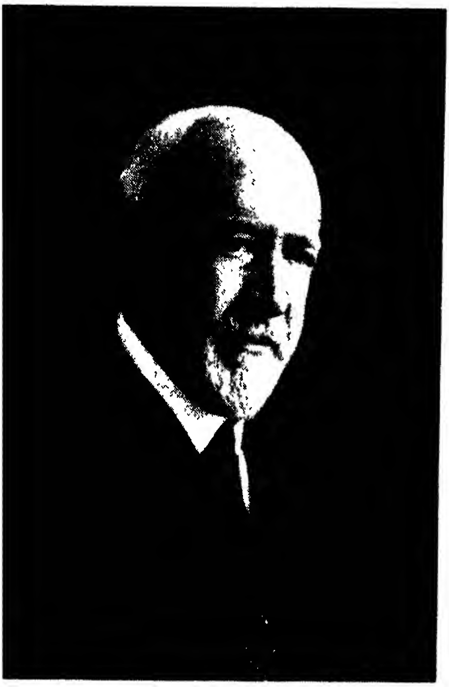
the Institute an Examining Body and which has established the qualifications of A.T.I. and F.T.I. upon a high plane; (*f*) certain minor matters even were dealt with, e.g. the Institute's seal and its telegraphic address; (*g*) an Institute Medal, of which the first recipient in 1921 was Mr. J. H. Lester and whose services those of the four gentlemen now to be similarly honoured, may be equitably ranked; (*h*) and lastly an Annual Lecture--suitably termed the "Mather" lecture--which has now in association with it a list of names of lecturers, second to none in parallel circumstances.

The proposed "Warner" medal, as I have said, forms another step in the path of progress, and recently the Council have decided to push on at once with the Scholarship Scheme evolved by the Propaganda Committee for which a special grant of £5,000 has been graciously donated by the Cotton Reconstruction Board. At my suggestion the Propaganda Committee, through the Council, have nominated Mr. W. T. Boothman, Chairman of the Lancashire Section of the Institute, who is well-known in Bolton as a practical manufacturer, and Mr. Samuel Watson of Hyde, who has been examiner in cotton weaving for the past 25 years, to formulate the scheme. In the hands of these two gentlemen, who are so thoroughly acquainted with every phase of the industry, there is no doubt in my mind that a worthy scheme will eventually be put into effect. But still much remains to be done.

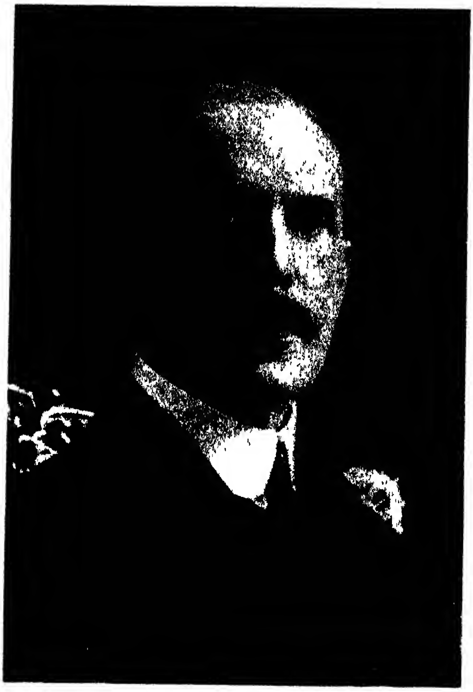
It was in June 1918 that the award of an Institute medal appeared as an item in this scheme, and from then onwards the idea was retained and developed. It has to be recorded that Mr. George L. Craig contributed direct financial assistance to the provision of the design and dies for this medal, and I think those who receive this award, and those who see its reproduction in the *Journal*, will agree that it was well done, and is a worthy symbol of this Institute's appreciation for services It was decided first to award the Medal to Mr. J. H. Lester, and Lord Emmott kindly attended a luncheon at the Midland Hotel, on 11th October 1921, to make the presentation. I may perhaps best make clear to you the grounds upon which this award was made by quoting his lordship who said "It gives me great pleasure to present the first Medal of the Institute to Mr. Lester, who I understand was mainly instrumental in founding the organisation. It has certainly been to Mr. Lester's wide outlook that the breadth of the Institute's constitution has been due." I think we can heartily endorse this. It has not been forgotten, however, that others were associated with Mr. Lester in the early days of foundation, and in recognition of his services, Mr. George Moores, our first Secretary, was made an Honorary Life Member of the Institute. One of our Presidents, Mr. John Emsley, of Bradford, to whom I have already referred, was made the first Fellow of the Institute and presented with an illuminated address and copy of the Royal Charter he did so much in securing for the Institute. Some of us have felt, though, that still further recognition must be given to those who "bore the heat and burden of the day" when the Institute was small, comparatively unknown, and very poor, and moreover was distressed as all similar institutions were, owing to the incidence of the war. The presentations which I have to ask our respected President, Lieut.-Col. Dobson, now to make are to mark the Institute's full appreciation of the services of four stalwarts who have been staunch supporters of our organisation since its inception.

I ask you, Sir, to award the Institute's Medal to John Crompton (his daughter and his brother are here to receive it on his behalf), William Frost, Frederic Robert McConnel, and Thomas Fletcher Robinson.

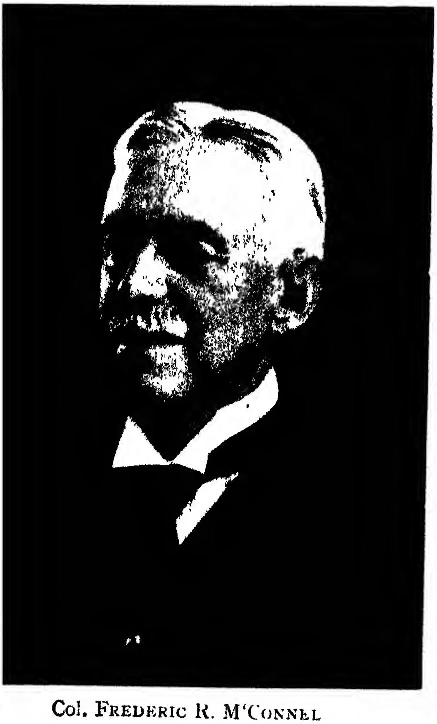
The President said he did not think that the work these gentlemen not only had done, but were doing at the present time was fully realised. Their interest in the Textile Institute had not waned but increased as the years had gone by. They were the backbone of the Institute, and their names were unconditionally picked out of the list of members as being worthy to receive this just tribute from the Institute.



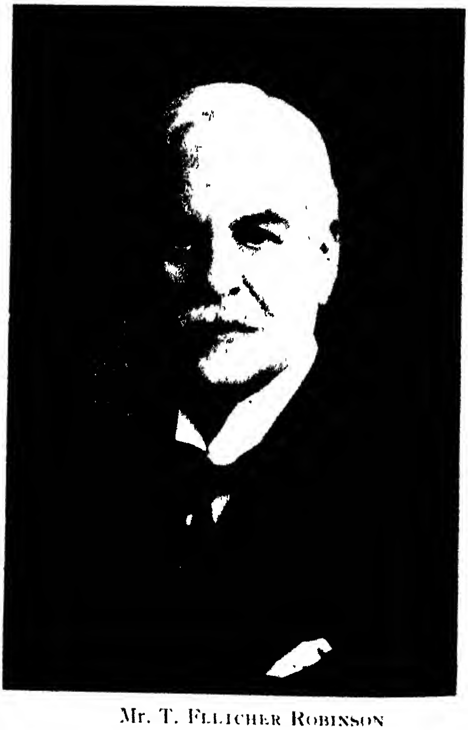
Mr John Crompton



Mr. William Frost



Col. Frederic R. M'Connel



Mr. T. Fletcher Robinson

AWARDED THE TEXTILE INSTITUTE MEDAL, MAY 1930

The Medallists

John Crompton—Mr. Crompton was a foundation member of the Institute. He is well-known for his activities in the textile trade and technical education. He has served as Chairman of the Council of the Textile Institute, and in memory of his son endowed a scheme for the presentation of prizes to producers of albums of fabrics which are judged for novelty, design, and general utility. He is also a Fellow of the Institute.

William Frost—A prominent member since its foundation, Mr. Frost has served as Honorary Secretary of the Institute since 1914. He has given great public service to his native town, Macclesfield, where he was in business as a silk throwster from 1873 to 1926. For a number of years he has been a Vice-President of the Institute.

Frederic Robert McConnel—Enrolling as a member of the Institute at its foundation, Colonel McConnel became Hon. Treasurer in 1912. He relinquished the office in 1914 when his military duties called him away. On the death of Sir Herbert Dixon in 1920, he was elected President of the Institute, and was re-elected for the following year—1921-22. In 1926 he was made a Fellow.

Thomas Fletcher Robinson—Also a foundation member of the Institute, Mr. Fletcher Robinson has long had an interest in the textile industry. In 1914 he became Hon. Treasurer of the Institute, and has held this position until the end of 1929—a period of 15 years involving much arduous work. In 1926 he was elected a Fellow of the Institute.

The President then made the presentations. Mr. John Crompton being unavoidably absent, the medal was received by his daughter, Mrs. Bryers, and his brother, Mr. W. B. Crompton.

Mr. W. B. Crompton replying, expressed appreciation on his brother's behalf for the consideration shown him. It was nice, he said, to be made aware that your efforts in a particular sphere had been appreciated. Most of Mr. John Crompton's work had been in the direction of education. He had encouraged the efforts of others by disseminating knowledge in the subject in which he was personally engaged. Speaking generally, he thought they had become more open as years had gone by and more generous in their dissemination of knowledge one to another. He thought that feeling made for the welfare of the industry. His brother would appreciate the medal which had been given to him, and he thanked the Institute on his behalf.

Mr. William Frost said his connection with the Institute was due to his cousin, the late Professor Fox, a name which was honoured in the textile industry. When 20 years ago Professor Fox asked him whether he would join the proposed Textile Institute, he promised to do so, but he did not think he was laying himself out for 20 years of work. Still less did he think that at the end of 20 years he would be honoured by the gift he had received that day. He would like to say that his connection with the Institute had been a really pleasurable period not only for the work they had all tried to do and for the small beginning they had, the slow growth principally due to the war, the period of comparative success which they had had, but also from the fact that he had all the way through met friends, and this had appealed to him perhaps more than anything else. It also afforded him real pleasure that the men who were growing up to continue the work were fully equipped for the task they had before them. He had been impressed at Council meetings by the breadth of thought and vision of the men who had been elected during the past few years. He only hoped that the success of the Institute would be greater and greater as the years went by.

Colonel McConnel said he received the medal with great pleasure and satisfaction and what one might term reverence. He went there with some little diffidence. He had met a friend who said "I see you are going to Bolton tomorrow to a prize-giving." He did not accept the medal as a prize for anything he had done. He hoped this system of giving medals might be an encouragement

to others to work for the Textile Institute and endeavour to make it still more valuable than it had ever been before. One of the greatest pleasures he had was that his old colleagues, Mr. Cromptom, Mr. Robinson, and Mr. Frost had been associated with him. He did feel that they deserved their honour to the greatest extent. One thing they must bear in mind was that it was no use having technical education unless it could be put to practical use. It was the work of the Textile Institute to encourage scientific training in order that those engaged in the textile industry of this country might not only be able to hold their own but could regain their former power. He thanked the President for handing him the medal, the Council for having honoured him, and wished success to the Textile Institute in the future.

Mr. Robinson expressed his high appreciation of the honour they had conferred upon him. He said it was extremely difficult to form a new organisation. He recalled the efforts of men like Mr. Lester, Professor Barker, of Leeds, and others which had been followed by splendid results. Despite their moderate means he thought they had to congratulate themselves that in the course of 20 years it had been possible to establish an organisation with such an influence for the good of the industry. It had advanced so far as to obtain a Royal Charter. The Fellowship and the Associateship of the Institute were being sought by the younger men as the hall-mark of fitness to occupy the best positions in the industry. He had made many valuable personal associations, which had enriched his life. The Institute had been worthily served by its Presidents. It was a great ideal which Sir William Mather brought forward, and he was very glad to have been one of those taking part. Sir Frank Warner, a most gracious President, was another gentlemen of high ideals. Considering all the difficulties, he thought on the whole they had succeeded splendidly. It was gratifying to see that the younger men, better qualified by their better education, were coming forward to carry on the work, and he looked forward to a distinct advance.

INSTITUTE LUNCHEON

After the Annual Meeting, members had lunch at the Pack Horse Hotel, Bolton. The President occupied the chair and the guests included Councillor R. E. Roberts, Mayor of Bolton; Councillor W. Russell, Chairman of Bolton Education Committee; Major Colin Shaw, President Bolton Chamber of Commerce; T. Bolton, Chairman of the Bolton Building Employers' Federation; T. O. L. Chorlton, Vice-Chairman Bolton and District Engineering Employers' Association; S. Parker, Town Clerk, Bolton; F. Wilkinson, Director of Education, Bolton; H. G. Hughes, Director Cotton Trade Statistical Board; Albert Edge, Secretary Bolton and District Card and Ring Room Operatives' Provincial Association; R. H. Longworth, Assistant to Director of Education; and Wm. Wood, Secretary Operative Cotton Spinners' Provincial Association.

The President proposed the loyal toast and then introduced the Mayor (Councillor R. E. Roberts).

The Mayor expressed his pleasure at being associated with the Textile Institute. This pleasure was increased because he had beside him a gentleman of his own town whom he had known for a long time. He was very pleased that Colonel Dobson had been elected President for a second term of office. He gave a hearty welcome to the Institute members to Bolton, but he regretted they found Bolton's great industry in such a depressed state. He was reluctant to discuss the causes for this depression, as he must not touch on the political side of the question, and this limited the subject. The taxation of the country required serious consideration. Whatever the causes of the depression, the solution must be the work of the leaders of the textile industry. He was certain they would have to "grasp the nettle" to raise the industry to a state of prosperity. In conclusion, he expressed the wish that in the near future some definite solution to their problems would be found.

The President thanked the Mayor for giving them a civic reception. His Worship had gone further and invited the delegates to tea in the Town Hall after the lecture in the Technical School. They appreciated this civic acknowledgment of the Textile Institute. The Institute held a Royal Charter. It was not only a Lancashire Institute, but it had flourishing sections in London, Scotland, and other places and new sections were being formed. It was suggested that one be formed in the Midlands. Not only did they represent Great Britain, but they had fellows and members in nearly every country in the world. As members of the Textile Institute they were inclined to hide their light under a bushel. He thought it was up to them to let it be known that they belonged to an organisation holding a Royal Charter and represented throughout the world. The Institute had done much in its 20 years of existence. The *Journal* was well-known and some members were quite satisfied to receive it as their only membership benefit, but by keeping in touch with Institute headquarters, membership could do more for them. In this way he himself had gained much valuable information. He appealed to members to utilise the Institute, and to try to get others to become members and support the organisation. He understood that outside Manchester, Bolton had the largest membership of any particular town. Wherever they went he hoped the example of the Mayor of Bolton would be followed and that the Institute would receive a civic welcome.

Mr. Frank Nasmith proposed the toast of "The Guests," and said that, like the President, he had often pointed out that they were not recognised as they ought to be. They were not as old as other institutes, but at the same time they had been "hiding their light under a bushel." During the time he had been Chairman, propaganda had been an important part of the work; invitations had been sent to other bodies, and as an old journalist he recognised the importance of getting the best possible press. They wanted their guests not only to enjoy their hospitality but to become canvassers for them and add considerably to their 1,550 members. They were putting into operation this year a scheme which concerned the educational side of the industry, and one which vitally concerned the operatives. This was a scholarship scheme and under it students whose circumstances had prevented their advancement would now have a chance for a full technical education. They had the valuable services of two gentlemen—Mr. W. T. Boothman and Mr. S. Watson—to formulate the scheme. If they could find the right type of young men, then he thought they would be doing a useful piece of work.

Councillor W. Russell, Chairman of the Bolton Education Committee, replying to the toast, congratulated the President on being re-elected for his second year of office. He wished to inform Mr. Nasmith and those gentlemen outside Bolton that they held classes for the preparation of candidates for the Institute's Associateship, and he also wanted to assure them that the Bolton Education Committee would only be too delighted to do what it could to help them along the lines of progress. It was not the first time that the Institute had been to Bolton as they were there on the occasion of the Crompton Centenary, and he hoped it would not be the last time. They would always receive a hearty welcome.

Mr. W. Wood, Secretary of the Bolton Operative Spinners Association, also replied, and expressed his pleasure in being associated with Councillor Russell in replying to the toast of the guests. He could assure them on behalf of the people he represented that he was very pleased to be with the members of the Textile Institute. As the Mayor had pointed out trade conditions were difficult and they would like to find a way out. He considered that the difficulties lay beyond the weaving sections of the industry. He was pleased to know that Colonel Dobson had been re-elected President; he had followed Mr. William Howarth who was another Boltonian and one who had achieved success by his personal determination. In Bolton they had a very deep-rooted affection for the Dobson family.

ANNUAL MATHER LECTURE

The Mather Lecture was delivered in the Mawdsley Street Technical College by H. G. Hughes, B.Com., Director of the Cotton Trade Statistical Bureau. The President, introducing Mr. Hughes, said that those who attended the Mather Lecture last year, would recognise that Mr. Hughes' lecture could be regarded as a continuation of the previous subject. The following is the text of the Mather Lecture.

RECENT INDUSTRIAL TENDENCIES—THE SUBSTITUTION OF KNOWLEDGE AND CO-OPERATION FOR INSTINCT AND COMPETITION

By H. G. Hughes, B.Com.

Last year's lecturer spoke to you of "Science and the New Industrial Revolution." He dealt with the progress which has been made, through discovery and invention, during the last fifty years, and emphasised the increasingly conscious need of industry for an ever broader basis of knowledge. This, he showed, can only be attained by the fullest co-operation between science and industry; by the extension of research, and by the willingness of producers to try new methods.

To-day's lecture will be largely concerned with the same sequence of events, though viewed from a rather different angle. The new industrial revolution has created at least as many problems as its original, and unless we face them soon, and with the intention of finding solutions, it is possible that the disturbance of society and distress to individuals which followed the inventions of Watt, Arkwright, and Crompton will be eclipsed by the consequences of the internal combustion engine, wireless telephony, or the automatic loom. The full effects of the earlier inventions were not felt until long after they had passed into general application in this country, and were beginning to be applied abroad.

It is difficult to understand what is taking place in our modern economic life without reference to the starting point of the movement which we call the industrial revolution. Strictly speaking, there is no such thing as a revolution in economic affairs. What actually happened in England during the eighteenth century was very similar in character, though not in degree, to what has been going on here and elsewhere during the last fifty years. The industrial revolution was not so much a turning point in history as the beginning of a period of increased activity and greater speed. In the eighteenth century, as in the nineteenth and twentieth, human ingenuity was seeking constantly for ways to overcome physical and psychological obstacles to progress. There were inventors in the cotton industry before Arkwright and Hargreaves, just as there were steam engines before Watt. From time to time, however, the accumulated knowledge and energy of the race seems to enable it to press forward more swiftly, and the impression is left of a door having been suddenly opened. But—

"Not by eastern windows only,
When daylight comes, comes in the light,
In front, the sun climbs slow, how slowly,
But westward, look, the land is bright."

One of the disadvantages of using the picturesque term "revolution" is that it fosters the assumption that progress consists in occasional leaps, separated by long intervals of rest, or what is called normal movement. Since the term is so generally accepted, however, it will be convenient to use it here, subject to the reminder that it does not accurately describe the movement which began in England a hundred and fifty years ago, and which spread more slowly to other countries. This movement, in fact, still continues, and what we call the new industrial revolution is only its latest phase.

The original revolution was characterised by two main features. In the first place, production was speeded up and made much more efficient by the series of inventions and discoveries which in Lancashire are associated with the names of Kay and Arkwright, Hargreaves, Crompton, and Cartwright. Outside Lancashire, you will remember, there had been the discovery of iron smelting by means of coal, and the application of steam power to machinery.

The other characteristic of the period was its insistence upon free enterprise, under the inspiration of Adam Smith. It is possible that Smith's great doctrine of "natural liberty" appealed to some innate quality of independence—some sturdy spirit of self-help—among the people of these hills and valleys. At all events, for the next hundred years, or more, Lancashire and Yorkshire led the world in adherence to the principle of free competition.

Breaking, one after another, the shackles of the mercantile system, they attained at length to that state of economic liberty in which, as Smith had foretold, "Every man, so long as he does not violate the laws of justice, is left perfectly free to pursue his own interest in his own way, and to bring both his industry and his capital into competition with those of any other man or order of men."

It must be remembered that Smith's protest was only partly directed against customs duties and similar barriers to external trade. In George III's England, and still more in Louis XV's France, and in the Germany of four hundred petty princes, production and trade were still trammelled by many feudal restraints. Compared with other countries England was relatively free from the worst forms of restriction upon internal trade, and so was able to turn her main attention to the removal of external barriers. In France, however, where the State still prescribed, not only the goods which manufacturers should make, but in some cases the very machinery by which they should be made, and in Germany, where almost every noble took his toll from trade, it was natural that the first efforts for reform should be to remove these anomalies. In considering the progress which the principle of Free Trade has made in different countries it is only fair to remember the distance which had to be travelled in some of them. England had the advantage of starting with freer institutions, and although other countries have never quite caught her up in their attitude towards the freedom of external trade it must be admitted that they have gone a long way towards establishing free enterprise within their own borders.

The main consequence of the industrial revolution was that it enormously cheapened production, and so, in spite of many errors, and much hardship to those whom it employed, it materially increased the world's resources. Whether consciously or not, the masters of the new machinery followed the basic maxim of the new economic teaching, that "consumption is the sole end and purpose of all production; and the interest of the producer ought to be attended to only so far as it may be necessary for promoting that of the consumer." If cheapness and a previously unattainable range of products were in fact the consumer's real needs, he, at all events, had no reason to complain of the changed order.

During the nineteenth century the population of England quadrupled, that of Europe and Asia increased 133 per cent., and that of America 2,000 per cent. To a large extent the new pace of production and the stream of productive inventions were responsible for this increase. Throughout the earlier part of the century successive improvements in production and transport were constantly extending the limits of the available markets. An increasing proportion of the world's population was being brought within reach of the manufactures of this and other Western countries; at the same time, more efficient production was offering consumers increasingly better value.

Throughout this period, therefore, the principle of free competition met with almost unqualified success, since demand was always a little ahead of supply.

It is only within the last thirty or forty years that the limitations of competition have become obvious.

During this period the methods of Western industry have been applied in India, China, and Japan. Although technically these countries have benefited by the longer experience of the West, their labour conditions and the status of the worker appear to be similar to those which marred the introduction of the factory system in England, and which, with few exceptions, have characterised its introduction in other countries. The result has been that with almost equivalent machinery, but lower social standards, the latest outposts of the industrial system became almost immediately serious competitors of the older centres. This fact, combined with improvements in industrial technique, has brought us to a position in which it appears that the resources of production have outstripped the capacity of consumers. I am talking particularly of the textile industry, but similar conditions apply in nearly all the basic industries, as may be seen from the vicissitudes of coal, iron and steel, and shipbuilding, to mention only three industries, during the last ten years.

It is useless to speculate on what would have happened but for the war. The tendency towards saturation was apparent long before 1914. It is true that the war, by diverting production from its normal channels, and by severing the links which keep the world's economic system moving in some sort of harmony, obscured the trend of events, even as it accentuated the movement by arbitrary expansion of productive capacity for its own needs. Within the last ten years, however, the problem has been unmistakable, and its importance is now beginning to be recognised.

The governing factor in the situation is probably the unequal development of agriculture, as compared with industry. So long as the world held empty spaces which could be settled and put under the plough, and so long as improvements in farming could give an increased yield per acre, the fact that agriculture was lagging behind industry in its methods of production tended to escape notice. In terms of actual production agriculture has certainly kept pace with the needs of industry, or, rather, of the world's population. There is, in fact, a surplus of most foodstuffs and of many agricultural raw materials, which has persisted, despite the efforts of Governments and producers during the last four or five years. This surplus exists merely because of the mal-adjustment of our system of distribution, and does not imply that the world is over supplied in foodstuffs and raw materials. It is a problem of dislocation and not of over production.

Table I

Indices of World Production

	Wheat	*Maize*	*Rice*	*Cotton*
1909–13 average	100·0 ...	100·0 ...	100·0 ...	100·0
1924 (1924–25)	94·2 ...	93·6 ...	110·4 ...	110·6
1925 (1925–26)	107·1 ...	113·4 ...	109·5 ...	124·6
1926 (1926–27)	110·5 ...	108·5 ...	109·0 ...	126·1
1927 (1927–28)	112·2 ...	106·7 ...	109·3 ...	104·6
1928 (1928–29)	132·1* ...	108·8* ...	106·8* ...	115·4*
1929 (1929–30)	93·3* ...	112·6* ...	102·5* ...	119·6*

* Provisional figures (International Institute of Agriculture).

To anyone engaged in industry it may appear strange that such a surplus should have been maintained in the face of the downward tendency of agricultural prices as compared with industrial prices.

Table II (a)

Wholesale Prices of Agricultural Products

(Annual index numbers based on monthly average prices at markets stated)

AVERAGE 1924–26=100

		1925	1926	1927	1928	1929
Wheat.	Winnipeg—No. 1 Manitoba Northern	112	102	101	92	91
	Chicago—No. 2 Red Winter	116	101	90	101	85
Maize.	Chicago—Contract grades	112	82	95	106	102
Rice.	Rangoon—Big Mill Specials	95	101	94	85	85
	Tokio—Musashi	107	95	90	79	74
Cotton.	Alexandria—Sakellaridis g.f.	100	71	95	113	103
	New Orleans—Middling	102	74	76	86	82
	Bombay—M.G.F.G. Broach, fully pressed	101	74	81	85	79
Wool.	Australia—Greasy export	97	80	87	89	*57

* November 1929.

Table II (b)

Wholesale Prices of Manufactured Products

(Annual index numbers based on monthly average prices at markets stated)

AVERAGE 1924–26=100

	1925	1926	1927	1928	1929
Steel rails—London	100	94	99	99	99
Sulphate of ammonia—London	98	98	98	98	97
Portland cement—United States	100	97	94	93	89
Cotton yarn—Manchester—32's Mule twist American	74	101	76	80	77
60's Cop twist Egyptian	81	113	82	86	80
Cotton cloth—Manchester—32 in. Printer	80	103	81	82	80

A partial explanation of the failure of agricultural prices to recover their pre-war balance with the prices of manufactured goods is afforded by the fact that agriculture is a comparatively unorganised and decentralised occupation. It is carried on for the most part by relatively poor people who are compelled by necessity to make the fullest possible use of their land, so that they have not the same freedom of choice as industrial producers in deciding to reduce their expenses by restricting their production. Indeed, since domestic labour, that is, the labour of the farmer himself or of his family, enters largely into agricultural production, the farmer has less inducement than the industrialist to reduce the number of persons employed. Farming of any kind is generally a more hazardous occupation than industry. There is always bound to be some uncertainty as to the size and quality of future crops, which lessens the attractiveness of proposals to restrict production in order to maintain prices. The farmer can never be quite sure what acreage will be necessary in any particular year to yield a crop of given size and standard.

Mechanical improvements in industry have not been matched in agriculture, although much more labour-saving machinery is now being used. This, however, has not affected the methods of agriculture in such large and highly populated

regions as Africa and Asia. For a large part of the world's population, therefore, increased effort does not bring a proportionately increased profit—in other words, much of the world's agriculture is subject to the operation of diminishing returns.

Moreover, the demand for foodstuffs, which form a large part of agricultural production, is relatively inelastic; once the point of sufficient supply has been reached, further reductions in price are unlikely to evoke a corresponding increase in demand. If the average consumer needs at most seven loaves a week, the fact that bread is abnormally cheap will not induce him to buy more. On the other hand, a substantial reduction in the price of textiles might make the man who wears one shirt a week consider an addition to his wardrobe. The scales appear to be unduly weighted against the farmer.

The position, briefly, is that agriculturists as a whole are too poor to buy as freely as they might the products of industry. But agriculturists form more than three-quarters of the world's population, and represent in the mass a substantial part of the world's total demand for goods of all kinds. Their restricted buying power has led in turn to a reduced demand for industrial goods with lower prices and greater unemployment. The vicious circle is completed by the tendency of production on a reduced scale to raise costs, and so to delay the return to a healthier balance between industry and agriculture.

The problem, both for agriculture and for industry, is to lessen the gap between their respective price levels.

Farmers can either restrict their production until the world's demand for foodstuffs and raw material brings prices up to a level which will pay them better, and enable them to buy industrial goods more readily, or they can take steps to put the production and distribution of their crops on a more efficient basis.

Industrial producers have nothing to gain by restricting output, since their troubles are not due to low prices so much as unprofitable margins, even on prices which are, generally speaking, high in relation to the customers' poverty. They have, however, the same alternative as the farmers, namely, of reducing their costs by improvements in technique and organisation.

There have been several attempts among producers of foodstuffs and raw materials to strengthen their position during the last few years by restricting output. Not only cotton, but wheat, rubber, coffee, cocoa, tin, and nitrates have been subjected to experiments of this kind, all of which have ended in failure. In the long run it is always difficult to maintain a position of artificial dearness when buyers are aware of the existence of large stocks, and are prepared to buy on a hand to mouth basis until prices move in their favour.

And behind the large buyers who operate in the great organised markets stands the final consumer, the Indian peasant, the English spinner, or the American cotton farmer. Individually he is helpless and unorganised, but in the mass he invariably defeats, sooner or later, those who forget that consumption is the sole end and purpose of production, and that the producer's only claim to consideration is the service he renders the consumer.

Within recent years more emphasis has been laid upon this aspect of the industrial problem, and efforts have been made in different countries and in various industries to bring about such changes in methods of production as will not only yield producers a better return upon their efforts or investments, but will make their goods cheaper, more accessible, or more attractive to the customer.

These efforts have taken various forms, ranging from financial amalgamations between producers to arrangements for the collection of information, joint discussions of the facts, and, frequently, concerted action on the conclusions to which the facts point. Sometimes these arrangements have reached beyond the boundaries of a national industry, and have resulted in working agreements between producers in different countries.

These international agreements again vary from complete trustification of an industry down to associations for the exchange of information. There is

also a considerable variety of form among purely national organisations of producers, from the co-operative type to the price fixing federation.

The main purpose of this lecture, however (I am afraid you will think I have been a long time in coming to it !), is not to describe the activities of combines and amalgamations so much as to show the movement towards common action by groups of independent producers. The merits or otherwise of free competition are being widely discussed in many industries and many countries. There is a tendency to doubt its efficiency and usefulness under some of the conditions which govern industry to-day. Industrial and commercial organisation appears to be taking a new direction, and to be inspired by different principles from those which have been its motive during the last hundred years or so.

Perhaps there is no community in the world to whom the new ideas are of greater interest than to those who are engaged in the textile industries of Lancashire and Yorkshire, since, as I have tried to show, it was in these industries that the principle of free competition found its first and stoutest champions.

It is more than a question of interest, it is a question of supreme importance for these industries whether the new ideas differ radically from the old ones, and if so, to what extent they are likely to become permanent features of our economic system.

It is a mistake, I think, to regard them as alternatives to the principles of competition and individualism which have for so long characterised industry, especially in these two counties. Instances could be multiplied to prove that the principle of co-operation is neither new nor abnormal. The germ of practically every type of industrial organism which flourishes to-day can be traced at least half a century back. In fact, we need not go outside Lancashire to find examples of co-operative or co-ordinated action in industry or commerce. The problems of the cotton trade, in this respect, are really those of all other industries. I shall use examples drawn from the Lancashire industry, as typical of the general problems.

The Rochdale pioneers were not, perhaps, the inventors of co-operation, but they gave it its first great advertisement. At least three or four of the most successful amalgamations in the Lancashire cotton industry are over 20 years old. More than 30 years ago, also, was the first joint effort of the Lancashire cotton trade to obtain information about its Eastern markets.

There is a tendency in some quarters to regard the efforts which the cotton industry has made during the last few years through joint discussions, as emergency measures undertaken only because of the depressed state of the industry. Those who take this view feel that we are passing through a dark and difficult period, during which it may be useful to go hand in hand, but they look forward to brighter days when each will be free to go ahead at his own pace, leaving the weakest to take care of themselves. This is a false and dangerous belief. The pace of industry as a whole is set by the slowest, and its strength is determined by that of the weakest. The case for co-operation and frankness even between competitors is not based on sentiment, but on common sense and self-interest. The old utilitarian principle, that enlightened selfishness amounts to much the same thing as perfect altruism, still holds good. Its interpretation, however, has been somewhat broadened by adversity, and there is a greater zeal for enlightenment than formerly.

In this quest the resources of industry have been greatly extended by recent developments in economic analysis, and in the application of statistical methods. Whereas fifty years ago periodic economic crises, with their alternation of boom, panic, depression, and painful recovery, were accepted as inevitable, the tendency to-day is to inquire how far their effects can be minimised by pooling knowledge about the conditions which cause them, and by combining efforts to counteract them.

It is being realised more and more clearly, as investigation proceeds, that many of the factors which help to create trade crises are not innate in the economic

system, but are largely psychological. When prices weaken, people fear the worst, and act on their beliefs. At other times, optimism transcends caution, and prices move in sympathy with human hopes, instead of in relation to demand and supply.

If for fears and hopes we can substitute some degree of certainty, it may reasonably be expected that fluctuations in prices, production, and employment would become less violent, and therefore less harmful. This is the basic argument for industrial statistics, and experience shows that it is not an idle one. The cotton industry has set an excellent example to other industries in this respect. Its international statistics of mill consumption and stocks of raw cotton are not only the best of their kind, but were for many years unique.

We cannot rest on our oars, however, since the stream of events is never still. There must be constant efforts to improve and extend knowledge, in economic as in technical matters. During the last few years there has been a considerable advance in other industries. British coal production is recorded weekly on a compulsory basis. The iron and steel trades have a voluntary return of production monthly. There is an index of activity for the woollen and worsted trades, covering most of the industry. Various sections of the cotton industry compile figures relating to their own activity, but up to the present we have no general index for the whole industry. One result of this deficiency is that we know less of the trade of our home market than we do of our markets in Asia or South America, although the home market represents about one-fifth of our total trade.

Production is not the only avenue to be explored. Marketing presents an equally important problem. We know the movements of imports into our chief overseas markets, and in some cases we know the local production. We know very little, however, about the capacity of our various markets, and in consequence there are recurrent periods of overstocking in nearly all markets. This is partly due to insufficient knowledge and partly to lack of co-operation. If producers and merchants working for particular markets could know the total value of orders booked, for instance, they would have a better guide than they have now to the probable trend of the market.

In technical knowledge the British cotton industry is at least as far advanced as any of its competitors, and probably some way ahead. In knowledge of its own business position, it has a long distance to travel before it can compare with such countries as India and Japan. America is still further ahead in respect of information on the movements of production and trade. We know, in fact, more about the position and progress of the cotton industries of Japan, India, or the United States than we do about the state of our own industry in Lancashire.

We are on the eve of a long and difficult period of reorganisation and reform in the Lancashire cotton industry. A similar experience probably awaits the wool textile industry. There is every indication that, on both sides of the Pennines, a process of grouping, amalgamation, and retrenchment lies ahead. In what spirit is it going to be carried out?

If the spirit of ruthless and reckless competition continues, in ten years' time the cotton industry—and possibly the wool industry—will be in a more dangerous position than to-day. The number of competitors will have diminished, but the power of those who survive will be much greater. If this is to be directed internally, against other units or other sections of the same industry, it will almost certainly fail in its main purpose of getting British goods into the hands of as many consumers as possible.

Fortunately in the cotton industry, of which I am better able to speak than of wool, there is every prospect that the opportunities of the future are not going to be wasted in useless internal struggles. For five or six years the industry has been examining its problems through the Joint Committee of Cotton Trade Organisations, and more recently it has had an external inquiry by a Cabinet

Committee, whose report should be available almost immediately. Five or six years may seem a long time, but I believe it has been time well spent, in reaching conclusions on the questions of broad general principle, which, in an industry as large as ours, must be settled before action can be taken. Within the last two or three years, moreover, action in various forms has begun, and doubtless when we know the recommendations of the Government Committee, it will continue rather more rapidly.

I do not know, of course, what the Government report will contain, but I am confident that it will endorse the policy of co-operation and investigation which has already been adopted by the industry.

That policy involves two main principles. The first is that we should be able to measure our problems, wherever their character makes measurement possible. In addressing the members of this Institute, I need not labour the point that in economic, as in scientific inquiry, a little exact knowledge is worth more—or at least is safer—than the most inspired guesswork.

The second vital principle is that when all the information available has been examined there should be concerted action in applying it, in such a way as to obtain the best results, not for a single firm, or even a section, but for all engaged in the industry.

It must be remembered, too, that the interests of the industry are bound up with those of other industries, in this country and abroad. For this reason the work of co-ordination must be both national and international. The efforts of the League of Nations and the International Chamber of Commerce for a freer exchange of information and opinion between the business men of different countries have done much to illuminate the problems with which industry is faced in all countries.

The International Cotton Federation, which led the way in the direction of co-operation between competing industries, has lately turned its attention to the question of propaganda. The National Cotton Week which is now being held is the latest proof of what can be done by a combination of resources and efforts in a single direction.

The future course of industrial co-operation depends on an alliance between technical and economic research on the one hand and men of vision and goodwill on the other. If it is agreed that the problem before industry is mainly a problem of distribution, it is probable that some amount of apparent sacrifice will be needed.

The limitations of free competition in marketing are more obvious than in production. Competition between producers tends to stimulate efficiency, and the opportunities for improvement in technique or organisation are much greater than exist in marketing. Competition in marketing tends to become a mere test of bargaining power in which the victory is not necessarily to the most efficient.

Marketing enters into every stage of a highly stratified industry like cotton, and it is essential therefore that it should be conducted in such a way as to develop efficiency rather than the instinct of the chase.

Broadly speaking, supply in the cotton trade appears to exceed demand, but that is only a superficial view. In reality demand is always ahead of supply, and the problem for producers and distributors is one of finding where new markets lie. The probability is that more and more energy will be put into this channel and less into attempts to increase the trade of a particular firm or the profits of a particular section, without increasing the total return to the industry.

The Joint Committee is at the moment conducting a number of investigations with a view to discovering new outlets for Lancashire goods. All sections of the trade, both employers and employed, are taking part in these inquiries. Although they cover a wide variety of problems and of conditions these inquiries have at least one important feature in common;, they have all brought out the possibility

of achieving substantial economies, both in production and marketing, by co-ordination of effort and exchange of information.

We have not yet reached the position of some American industries, which have been able to introduce extensive simplification and standardisation, and so to reduce that part of cost of production which is due to unnecessary variety. We are, however, beginning to find the benefit of standardisation and mass production, and the probability is that an increasing proportion of Lancashire trade will be done on the same basis as that of our competitors, namely, of finding what consumers like, and then producing the nearest approach to it that will give maximum efficiency in production and satisfaction to the consumer.

You may feel that I have taken you over a great deal of ground before coming to the gist of my subject. My only justification is that I have been commenting, so to speak, upon the end of an epoch. In a sense this has been a funeral oration on the spirit of free competition, although I have tried to show that free competition, like any other spirit, has not really died, but taken on new characteristics, mellower and more attractive than those with which it burst upon a carefully regulated world over a century ago.

My main concern has been to suggest that the substitution referred to in my title is less a matter of choice than of growth, that the world has developed in organisation and outlook to a stage at which the old labels no longer describe the features to which they are attached. Such bodies as this Institute have played, and must continue to play, an important part in securing recognition for the changes that are passing over our industries. A scientific spirit of inquiry, based upon a willingness to face realities, together with the patience, goodwill, and faith in the future of the industry, which have always characterised its leaders, are more than ever necessary. With these, and there is no reason to doubt their existence, we need not fear the ability of these old-established industries to adapt their methods to the times.

Professor J. A. Todd, the first Mather lecturer, moved a vote of thanks to Mr. Hughes. From what he knew of his previous work and his title, said Professor Todd, he expected they would have a good discussion of the advantages of information in the industrial arena. He hardly expected such sympathy for the agriculturists. He was glad it was now being recognised that the poverty of the agricultural people was the cause of our trouble to-day because they could not possibly buy our manufactured products. Every time he came back from America he was more sick of the social conditions in the American cotton belt. Things were very different in the Empire cotton fields. It was the proud boast that wherever Empire cotton was grown the lot of the grower and the worker always improved. That was true throughout the Empire; it was the reverse of true in America, and he thought it was one of the most important things to the American people as a whole to realise how bad things were in their own cotton belt and improve them. He did not want people to run away with the idea that there was a surplus of cotton in the world. From 1909 to 1913 happened to have been the last period before the war, and 1909 was a calamity for cotton; during the period there was only one big crop—1911. Since the war there had been three appallingly bad years—1921-1923—and from that series of years it looked as if we were always getting more cotton, but that was quite misleading. The position to-day was not that we have a surplus of cotton. We had never increased a quarter-of-a-million bales more than we had before the war, and that was not an over-supply. He supported Mr. Hughes very strongly in his plea for more knowledge, particularly in regard to the cotton industry. As Mr. Hughes had said, no trade had had more choice of statistics in the past, and he would like to say that no trade had suffered more, not from the non-use, but from the misuse of them. They were full of pitfalls, and the trade as a

whole had not taken the trouble to study them. Perhaps one could not blame them because people in business had something else to do. They needed more information about other ends of the trade. They were well supplied with raw material statistics and world's crops, but they were not sufficiently supplied with statistics at the other end. The Cotton Textile Institute of America was publishing, regularly, monthly statistics of the American cotton industry, production, shipments, unfilled orders. If only we had something similar! We had the International Federation's statistics of the world's consumption of cotton. How useful if we had these monthly as they had them in America ! The American Government published them every month. The whole position cried out for more knowledge on other points. We were in the position that the cotton trade did not like statistics; we did not believe in statistics and we did not like to give away information. We wanted to keep these things to ourselves. This was in marked contrast to America. We had a long way to go before we could collect the necessary material to complete the study of details; we must have more knowledge if we were to work out a cure for our problems. Mr. Hughes' plea for more knowledge and more publicity was one of the things which required stressing in the cotton industry, and he hoped that the Textile Institute would put its whole weight behind this plea.

Mr. H. P. Greg seconded, and said that Mr. Hughes had taken them away from their petty troubles, and given them a real reason why the world was so sick to-day. This was the upset in values between industry and agriculture, and they had to see if there was a way in which they could be remedied. It had always struck him as curious that they should separate so completely agriculture and industry when the difference between the two was so infinitesimal. The only difference between them was what they put in their mouths and what they put on their bodies—how they clothed themselves. Both were equally important in the growth and development of the human being. They were in the closest possible relationship, and to his mind that was the point which Mr. Hughes made—that we had to do everything we could to remove the barriers between these two immensely important phases of human welfare. He thoroughly endorsed what Mr. Hughes said about our being anxious to get knowledge and to our being more anxious to diffuse that knowledge. He was only too glad to allow anybody to inspect his own concern, and he did not mind his colour providing he was a reasonable being and in search of knowledge. As a result he had had the freest access to mills on the Continent and in America; much freer access than in this country. In those countries he had been well treated, and he did wish to press very strongly that he had received far more than he had given. He believed that going through the various mills abroad and in this country had been of greater value than any information he had been able to give to his competitors or the foreigners who had been over his mill. He was perfectly certain that Lancashire was quite wrong in her policy in trying to keep things to herself. The world was now too closely knit to look at industrial or agricultural problems nationally; we must look at them internationally. We must take a wide and broad survey, as Mr. Hughes had been showing them that afternoon. He could not stress sufficiently his gratitude to Mr. Hughes for his lecture. They had heard a very valuable contribution to the position in which Lancashire found itself to-day.

The resolution was carried with acclamation.

Mr. Hughes briefly responded.

NOTES AND NOTICES

The Annual Meeting: A Bolton Welcome

The Twentieth Annual General Meeting was marked by a gesture on the part of the Municipality of Bolton emulating that of Bradford in 1929. The Mayor of Bolton extended a civic welcome to the members of the Institute and their guests, and joined in the event to the extent of lunching with the Institute and of acting as its host at tea in the Town Hall. This friendly recognition on the part of the civic authorities was much appreciated and is felt to mark a new era in Institute progress. This meeting will also be associated in the minds of all in attendance, with the presentation of the Institute Medal to four members of that band of enthusiasts whose names are associated with the early years of the organisation to which they have given so much loyal service. Messrs. John Crompton, William Frost, Frederic Robert McConnel, and Thomas Fletcher Robinson, whose portraits appear elsewhere in this issue, need no introduction to their fellow members who will be glad to associate themselves with the President and Chairman of the Council in expressing the appreciation of the Institute for their services.

The Mather Lecture

The "Mather" lecture,[1] delivered at Bolton by Mr. H. G. Hughes in the afternoon of 7th May, immediately following the annual meeting and Institute luncheon was noteworthy in more than one aspect. It recalled vividly the lecture[2] delivered on a similar occasion at Bradford the previous year by Mr. H. T. Tizard and, in the minds of many, no doubt, the address[3] delivered in October 1925 to the Lancashire Section members of the Institute by Mr. J. H. Dawson. These three addresses together with that of Sir Joseph Stamp[4] recorded in the February issue of this year must, if studied in conjunction, afford much food for deliberation. A brief survey of the ground covered by these four speakers, men of widely differing occupation but of similar ability to see beyond the effect to the cause and from the cause to the remedy, may serve to draw definite and fruitful attention to some of those larger problems which, it is being increasingly recognised, must sooner or later be faced. Mr. Dawson, while in no wise minimising the advantages secured by the use of machinery—automatic or otherwise—postulated that man must, by direct or indirect labour, feed, clothe, and house himself. Machinery had had the effect of drawing man from his agricultural pursuits and of bringing about, in the machinery-supplied country, a surplus of production in manufactured goods. This surplus went naturally to the agricultural populations who paid for these goods in soil-won wealth. But when, in the first country, the state of over-production in machinery arose, then machinery too had to be exported and the heretofore agricultural population "enjoyed" the benefits of machines for itself and sooner or later reached the stage of producing an excess of manufactured goods for which a market had to be found. Such an unregulated progression must sooner or later "jam on the hub," said Mr. Dawson, "but before this actually does happen readjustment will be necessary." Indeed, he averred, such readjustment was overdue. Production in clothing was out of balance with production in food and housing. Machinery, automatic or otherwise, must be applied to these two aspects of man's struggle for existence. This is perhaps a very bald statement of what Mr. Dawson had to say, none the less it will serve if it indicates that as far back as 1925 a finger had been placed on the lack of balance between

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[1] Pages P90-P98 of this issue.

[2] Science and The New Industrial Revolution. H. T. Tizard. *J. Text. Inst.*, 1929, 20, No. 4.

[3] The Effect of the Introduction of Automatic and Semi-automatic Machinery. J. H. Dawson. *J. Text. Inst.*, 1925, 16, No. 11.

[4] The Latest Aspects of Rationalisation. Sir J. Stamp. *J. Text. Inst.*, 1930, 21, No. 2.

industry and agriculture as *a* prime if not *the* prime cause of the state of economic chaos in which Lancashire industrialists, among others of course, found themselves embroiled.

Mr. H. T. Tizard, who delivered the 1929 Mather lecture, presented another, and in terms of immediate action, more easily apprehended aspect of the situation. The industrial revolution of the nineteenth century was significant for the replacement, which it effected, of animal and human labour by machinery, and for the rapid development of coal resources. Mr. Tizard drew an interesting picture of this period of development which he showed to have taken place mainly in those industries which provided mankind with clothing and those which placed supplies of power and means of communication more readily to man's hand. "Agriculture," said Mr. Tizard, "gave way generally to industry." Here he showed in a sentence the accuracy of the view presented by Mr. Dawson, but he made then two very great contributions to a fuller and more acute comprehension of the subject by drawing a clear picture of the value of science not only to industry but to agriculture, and by indicating in no uncertain terms one of the greatest, if not the greatest, of the menaces humanity has now to face. He showed first how science and industry at the outset of the industrial revolution were not interdependent but had each exhibited unprecedented and simultaneous growth and discoveries. Gradually they had interlocked; industry had supplied equipment and funds; science had reciprocated with fundamental knowledge, and advice as to the elimination of waste and the avoidance of fruitless effort. What was now the part to be played in industry by science? "The old foundations (of science) are strong enough to bear a much more imposing industrial structure than exists to-day," said Mr. Tizard. "How much good is it (science) going to do us ?" Mr. Tizard's lecture constituted an answer, so far as time permitted, to this question and his instances of the value of the application of accurate knowledge in regard to the use of coal, in the fishing industry, and, potentially at any rate, in the manufacture of bricks were carefully thought out and adequately presented. But his second contribution, though since the circumstances placed limits on his subject, little more than a reference, was no less important. He said "nevertheless we remain almost powerless in the face of epidemic illnesses and chronic diseases which cause every year immense suffering, discomfort, and loss. "If," as he contended, "the ultimate aim of science applied to industry must be to raise the standard of living of the population as a whole," so must science, biological and medical science, applied to the problems offered to mankind by insect pests, parasitic, and bacterial diseases contribute her share not merely to raising the standard of living but to securing that mankind shall continue to live. In such a struggle, agriculture can do more than industry and it becomes the more imperative that the balance, now tipped against agriculture, shall be restored. Mr. Tizard pointed out too that men's minds are turning to the problems of reorganising the older industries on a more efficient basis. This he called the new industrial revolution and said a new name—rationalisation—had been invented for it. His definition of rationalisation was interesting in the light of the address of Sir Josiah Stamp to Yorkshire members in Bradford Town Hall on 9th January 1930. Mr. Tizard defined rationalisation as "a really comprehensive effort to reorganise the older industries in such a way as to lower the amount of human labour necessary to produce a unit of production, and to improve continuously the quality of that product." It is amazing that after these pronunciations, by Mr. Tizard and Sir Josiah Stamp, that rationalisation still means to the average man "amalgamation" and nothing else.

Mr. Hughes concerned himself with the same sequence of events as did Mr. Tizard, but viewed them from a different angle. The new industrial revolution has created at least as many problems as its original and unless we face them soon and with the intention of finding solutions, it is possible that the disturbance of society and distress to individuals which followed the earlier inventions

will be eclipsed by the consequences of the later epoch. The older revolution was the beginning of a period of increased activity and greater speed; both making their demands on health and vitality, be it noted. It is not the purpose of these notes to summarise Mr. Hughes' lecture but rather to direct more specific attention to a valuable pronouncement. It must suffice therefore to indicate the main theme in relation to the foregoing survey of the lectures by Mr. Dawson and Mr. Tizard. After discussing the two main characteristics of the older industrial revolution, Mr. Hughes touched on its effect, first in this country, in Europe and the United States and then on far eastern nations, India, China, and Japan. A result of the spread of western methods in industry into these countries is that they, with almost equivalent machinery, but lower social standards, have become immediately serious competitors of the older centres. The cycle of progress is beginning to "jam on the hub" and readjustment is surely long over-due. "The governing factor in the situation," said Mr. Hughes, "is probably the unequal development of agriculture, as compared with the industry." He shows how and why this situation has arisen, and concludes that the problem, both for agriculture and for industry is to lessen the gap between their respective price levels. He then discusses means that have been adopted and that are in existence to-day to restore, so far as may be, this lack of balance. His plea for the substitution of knowledge and co-operation for instinct and competition was a powerful one and it is noteworthy that such a plea should be made from the Textile Institute platform and in expansion and continuation of the two lectures referred to above. If food, clothing, and housing are to be provided for all without one section being exploited at the expense of another and if "the standard of living" is to be raised in a race that lives healthily and is not disease ridden, there may be grounds for pleading not only for the fuller use of knowledge, but for an Institute of Institutes to secure co-operation in the pursuit of these attainable but far-distant ideals.

Textile Institute Diplomas

Election to Associateships of the Institute have been completed as follows since the appearance of the previous list (April issue of this *Journal*).

SLATTERY, Edward (Manchester).
WYRILL, Ellis Firth (Castlemaine, Australia).

Institute Membership

At the May meeting of Council the following were elected to membership of the Institute—L. V. Bona, Carignano, Torino, Italy (Wool Piece Manufacturer); A. N. Bose, c/o Indian Stores Department, Harawala Building, Ballard Estate, Wittet Road, Bombay, India (Inspector); J. Lawrenson, 4 Leamington Avenue, West Didsbury, Manchester (Sample Clerk, Cotton Spinning and Doubling); J. R. Mudie, Delta Jute Mills, Sankrail P.O., Howrah District, Bengal, India (Mech. Assistant); T. H. Westwood, 34 Brompton Street, Oldham (Cotton Doubling Manager); V. E. Yarsley, c/o The Non-Inflammable Film Co., 136 Regent Street, London, W.1. (Chief Chemist); A. Draper, "The Beeches," Green Lane, Blackburn (Cotton Spinning and Manufacturing Director); R. Southworth, 19 Hampton Road, Great Lever, Bolton (Managing Carder).

THE JOURNAL OF THE
TEXTILE INSTITUTE

Vol. XXI JUNE 1930 No. 6

PROCEEDINGS

Irish Section

Meeting at the Municipal College of Technology, Belfast, on Thursday, 23rd January 1930; Mr. W. H. Webb presiding.

COSTS AND STATISTICS FOR THE LINEN TRADE*

By J. F. WHITEFORD

It is one of the idiosyncrasies of humanity that to what is in the immediate vicinity the least study is given. What is most apparent we fail to observe. And so it is that the valuable experience of the development of navigation has not been utilised in the management of business. The accepted principles in navigation are—

First—that a chart be prepared in advance of the route to be followed.

Second—that frequent calculations are made of the exact positions to ensure that the route is being followed.

Third—that when by reason of unusual circumstances the ship is driven off the course, steps are taken to return to it as soon as practicable.

No navigator is content to trust to the charts and instruments of a generation ago. Navigation is being constantly improved. New and better instruments are being developed, not so much for actually steering the ship, but to enable the navigator to check his position. No business executive can afford to refuse the means for improving executive control. What the charts and instruments are to the navigator, so costs and statistics are to the business administrator. What is true of individual businesses is true of an industry as a whole. To avoid misunderstanding it should be stated at once, that no cost system, however intricate or expensive, no mass of statistics, however voluminous, will ensure success in business. They are merely means to an end and not an end in themselves.

Now what is the end, the aim of business endeavour? What is the port toward which the course is laid, toward which all chartering and calculations are pointed? Or, is there to be no definite port, no definite course? Just a policy of drift and any port in a storm. No doubt everyone will say that the aim of business effort is to make a profit. And in this I agree, for after all, it is only common-sense. No business which does not make a profit can hope to exist. The man who sells for ninepence what it costs him tenpence to deliver may get a big turnover but he will have no profit.

By profit is meant net profit. That is the only profit that counts—net profit. For some unaccountable reason the term "gross profit" has been introduced into business nomenclature. And harmless as the term may seem, I am satisfied that its use has been the means of much harmful influence in business. Anyone can run a business and show a gross profit. A "gross profit" is merely the total receipts less a portion of the expenditures. All that is necessary is to leave out sufficient expenditures in the calculation for the result to be a gross profit. But

* The paper hereunder printed does not constitute the whole of Mr. Whitefords' lecture: the latter part is in abstract only.

it takes a real executive to show a net profit. No ship will run successfully without direction and control. No business will show a net profit without management. And net profit is what really matters.

None will deny that a business must make a net profit or cease to exist. But a profit is only a means to an end. It is necessary that we view business administration from a larger angle. A business must make a profit not only once but continuously, or cease to exist. All business effort should be directed toward the perpetuation of the investment. A profit may be made at the moment. A profit may be made during the current year. But are we to be content with consideration of the present only ? Have we not to visualise and anticipate the future ?

The perpetuation of the investment; this is the first charge against an industry. Many will not agree. Some will say that "wages" is the first charge, a contention supported to some extent by law. Others will contend that a dividend on "capital" takes priority else capital depreciation will result. But it is all important that the investment be perpetuated. All administrative policies must be directed toward that end. All costing and statistical research must have that for their objective. What, therefore, is the investment ? There are building, machinery, and material. These are tangible. There are market connections, technical knowledge, and goodwill. These are intangible but nevertheless of the greatest importance to the business. All must be considered if perpetuation is to result.

Now what is the purpose of cost figures? Mainly to show whether the line is making a profit. That is whether the price received is greater than the cost of the line delivered. For this purpose it is essential that cost figures be complete and reliable. *Complete*—in that the final figures contain all the elements of cost which require to be included in such calculations. *Reliable*—in that the assessment of charges in all of the operations be in direct relation to the service rendered in production and distribution. Thus the method of costing must provide for inclusion of all charges relating to every factor involved. Otherwise the profit resulting will not be sufficient to provide for the necessary perpetuation.

Further, if a line is sold at a price which does not yield a profit, it is necessary to know the amount of profit lost. That amount requires to be made up on other sales. Each loss must be more than compensated or a net loss will result throughout. The perpetuation of the investment involves more than the replacement of buildings and machinery, more than the replenishment of material and labour. There are many expenditures apart from these which will be discussed later. At the moment the main point is that the cost figures include all legitimate charges of whatever nature.

The sales price of each article sold is the only medium through which a business can secure the essential elements for sustaining life and growth. If the net proceeds of each sale are insufficient to replace the elements incorporated and to provide a reserve, then deterioration is bound to result. No ship is built just strong enough to withstand normal usage. Every part is designed to withstand all strains to which the exposure is known or estimated. Above this there is a factor of safety, a margin sufficient to accommodate unforeseen and unknown contingencies.

Everyone has a cost system. Some are elaborate and some are attempts at short cuts. Even the manufacturer whose cost result was minus 4·21d. had a cost system. That is, he had a formula in which the calculation was carried into decimal places. I doubt if any executive attempts to operate without some system of costing. But in all instances the question should be asked—Does this effort have for its ultimate objective the perpetuation of the investment ? Shall we think of the present only and not of the future ? The details of costing methods must vary with each factory. Rather than outline the details of any specified system I propose to make such suggestions as may prove useful in the reconsideration of any system in the light of the objective I have laid down.

Does your cost system supply you the information necessary for establishing sound policies for conducting the business ?; does it tell you which lines are profitable and which are not ?; the profit made on each line sold ?; the influence of quantity on the cost of any operation ?; or the cost of idle machinery ?

Will your cost system enable you to determine when a machine becomes obsolete, even though that machine is still in excellent running order ?; what expenditure can you afford to improve any particular process ?; how much will the cost of production be lowered if the sizes and qualities are reduced by 50 and the volume remains constant ? What will be the saving in cost if the time occupied by the material in process of manufacture is reduced by 50 per cent.?

Selling prices are usually determined by other factors than the cost of production. The sale of an article at less than the actual cost of production is a waste of capital. So the main function of any cost system is to disclose loss of profit. But costing research properly directed will disclose many things now considered necessary in the conduct of a business. Certain fundamental principles require incorporation in any costing system that serves the purpose. It is relatively an easy matter to determine if these principles are being followed. These are—

Operations are costed, not products.

Overhead and fixed charges are not assessed to the product or to the operation; but to the portion of the investment responsible.

Current, not past, expenditure is the basis of all calculations.

Material is charged to the product only through a stores record.

Use of the term "scientific" is avoided. Reliable is a better term. It may be worth while mentioning that costs may be accurate, but not reliable. That is the calculations may in themselves be accurate but the basis of the calculations be unreliable.

It may serve some purpose to correct any misapprehension in respect of "standard" costing and similar terms which may be confusing. In practice there are "estimated" costs, "actual" costs, and "standard" costs, all of which have a different meaning. "Estimated" costs are what costs "may be." "Actual" costs are what they really "are." "Standard" costs are what they "ought to be." The principles are the same in each case, the details differing only in respect of the results required.

Knowing the cost of the various operations, which figures include overhead and fixed charges as well as labour, "estimated" costs are prepared on the basis of the operations the article is to receive in process of manufacture. But by analytical research it is possible to determine how much the cost of each factor of each operation can be reduced. From these calculations the "standard" costs are compiled. "Standard" costing methods are therefore a further refinement of costing procedure. This is somewhat different from the general impression that "standard" cost systems refer to a common or uniform method of costing. It is not possible for a "standard" system to be introduced until "actual" costing practices have been developed to a rather higher degree.

It is necessary for each producer to know the costs of the various operations under his control. It is not sufficient for a factory executive to say that the cost of weaving is twice or three times the weaver's wage. He must know the cost of winding, of warping, of dressing, of drawing in, of weaving, and all the miscellaneous operations incidental to the production of grey cloth. It is not sufficient for the finisher to say that his cost is 2/– or 3/– per piece. He must know the cost of singeing, of stitching, of boiling, of souring, of beetling, of starching, and all the other operations under his direction. And in all cases each operation cost must include labour, overhead and fixed charges, and, if necessary, miscellaneous materials.

Neither buildings nor machinery are permanent. Neither will last for ever. Annual renewal and repairs tend to lengthen the life, but nevertheless there is a

steady shrinkage which must be provided for. Further, with the rapid improvement in methods of manufacture, machinery may easily become obsolete much before it has reached the point where it cannot function satisfactorily. A charge for obsolescence is to-day of greater importance than one of depreciation. Design is not permanent. What was in demand last year may not be wanted this year. Style is a greater factor than quality in influencing sales. Knowledge of costs in whatever detail will not serve the purpose if the article itself is out of fashion. If a market wears out it must be replaced. If a business is to remain healthy, the markets must be kept alive.

Perpetuation of the investment involves much more than renewal of machinery and buildings. Demand must be perpetuated, as otherwise production serves no purpose. Perpetuation of demand involves intimate knowledge of not only market requirements but also marketing methods. And this involves recourse to statistics. Hereafter Mr. Whiteford proceeded to discuss the part played by statistics in business and business research. He pointed out that statistics are only a means to an end; that research cannot be conducted without statistics and that these must possess four qualifications—

Statistics must be useful, reliable, immediate, and accurate.

From this he proceeded to show how it was only possible to estimate demands, establish production and to do so on a profit-making basis, when statistics of such character were available. It was urged that at present the Linen Industry suffered by reason of the lack of co-ordination between the production and distribution sections. Statistics were compiled on many things, said the lecturer, but not on what the manufacturer really wants to know: the history and cost of getting his product to the ultimate (and satisfied) customer. No manufacturer could collect these statistics individually; it was a matter for the whole industry. Some practical examples of statistical research were detailed and in some instances served to show that the research did not go far enough and did not therefore reveal the causes underlying the troubles thus investigated.

Finally Mr. Whiteford urged that everybody needs cost figures. Everybody has costs but these may or may not be reliable. Why not provide for the interchange of cost figures ? Comparison can be made of the cost of various operations without disclosing confidential information.

Why not join forces in market research and predetermine the requirements of each and every market open to the trade ? Why not ensure early information is obtained in respect of changes of fashion and its probable effect in all interested markets ? And why not provide for prompt advice of the stock position, of unfilled orders, of shipments en route ? And why not organise "mass selling" to combat "mass buying" efforts ?

Yorkshire Section

Joint Meeting with the Keighley Textile Society, at Keighley, on 10th February 1930.

FUNCTIONS OF THE BRADFORD CONDITIONING HOUSE

Mr. E. H. Townend, manager of the Bradford Conditioning House was the lecturer on this occasion. His paper was illustrated by a series of lantern slides. He commenced by a brief outline of the History of Conditioning or Testing Houses in which he pointed out that the first such organisations arose out of a conference in 1875 of delegates from the textile centres of France, Germany, and Italy, held at Turin. Shortly after this conference, Conditioning Houses were established by these three countries with Government support or the recognition of commercial organisations of the period and these establishments have been in operation ever since. In August 1891, the Bradford Conditioning House was established by the Municipal authorities of Bradford; it has since become one of the largest in the world.

The lecturer then gave an outline of the work of the Conditioning House, commencing with the arrival of the raw wool, tops, or yarns. The procedure and apparatus employed to ascertain the conditioned weight; the calculations made to arrive at the certified invoice weight and the standard regains recommended by the International Conference in Paris, 1927, were described.

Slides were exhibited of the conditioning plant, the certificate office, and the presspacking department. The lecturer next described the procedure for testing tops for gross scour loss. The percentage of fatty material, etc., thus lost is calculated and shown on the certificate issued; sometimes the percentgae of fatty matters and insolubles are required to be shown separately. Wool in the raw or greasy state is tested for yield or clean scoured weight and the methods employed were detailed by the lecturer.

Large quantities of yarn, in various forms, pass through the Conditioning House, continued Mr. Townend, and the tests applied include those for correct weight at standard condition, gross scour loss after commercial scouring, length, counts, and twists. Slides shown illustrated the yarn warehouse, and the testing machines and appliances employed. The Conditioning House laboratories had developed very considerably in recent years, said the lecturer, and the range of demand for their service widened extensively. Damaged wools and waste were analysed to find the causes of the damage; carbonised material is tested for acidity; tops and yarns are analysed quantitatively for oil, soap residues, and insoluble matters. Raw silk is tested for loss after de-gumming, and cloths for loading, fastness of dyestuffs, proportions of cotton, wool, silk, and rayons, etc. Cloths and yarns made to specification were also tested and the lecturer described the usual procedure followed as well as the importance of carrying out tests under known conditions of moisture content and atmospheric humidity. The humidity room, in which controlled conditions obtain, was described and illustrated.

The lecturer was heartily thanked for his interesting and instructive lecture and briefly responded.

London Section

Joint Meeting at the Chemical Society's Rooms, Burlington House, with the Society of Dyers and Colourists (London Section) on 21st February 1930

THE DIAGNOSIS OF COLOUR FAULTS IN FINISHED GOODS

This meeting was addressed by Mr. F. L. Goodall, of the Geigy Colour Company, who stated that he proposed to deal with the accidents that might happen before and after dyeing and their consequences. Wool and cotton were dyed in almost all forms and at every dyeing point had nearly always had some prior chemical treatment and subsequently had usually had to withstand chemical or physical treatment. In addition to these manufacturing conditions, the material was also expected to remain unaffected when stored in the hands of manufacturer, merchant, retailer, or the ultimate consumer, and in his or her hands must fulfil domestic requirements.

Mr. Goodall then discussed the tackling of any specific fault, and said that the first thing to do was to secure all possible information as to the incidence of the fault. Then it was necessary to consider all the manufacturing processes through which the fabric passed, and finally to make experiments on small samples of material to reproduce the fault. Then having reproduced the fault, comfirmatory evidence must be secured if at all possible. But though simple illustrations of the method could be given, said Mr. Goodall, it was not easy to convey the real difficulties involved; the crux of the investigation was the armchair investigation of the conditions to which the goods had been or could have been exposed.

Continuing, the lecturer considered the general chemical classification of conditions to which wool might be and usually was exposed in manufacture.

He first pointed out that, apart from dyeing, all normal processes involved the use of alkali; that wool was capable of forming a loose yet moderately stable compound with alkali; and that even prolonged washing in warm water might not suffice for complete removal of alkali. The result was that practically all slubbing or loose wool dyed pieces, such as all patterned goods, are slightly alkaline and all piece dyed goods are slightly acid.

The faults next enumerated by Mr. Goodall were those to be associated with the acid or alkaline condition of the goods. Cloths insufficiently washed-off; goods dried or not dried before dyeing; goods left lying about in a wet state; goods attacked by bacteria; and goods which have absorbed SO_2 from the atmosphere are all liable to uneven dyeing if the alkali is not thoroughly removed. Again pieces containing alkali if steam blown are virtually boiled in alkali and off-shade or stained goods are probable. Mr. Goodall drew attention to the enormous difference in dye-affinity possessed by alkaline wool steamed wet or dry; that steam blown wet will dye 77% darker than non-alkaline cloth, whereas steam-blown dry cloth dyes only half the depth of untreated cloth. In cases of goods being left alkaline no blame could be attached to the dyer. The remedy lay in the scourer's hands.

The lecturer said the second common cause of unexpected colour failure was the effect of sulphur and its derivatives. These faults were closely related to and sometimes dependent on a previous residual alkali fault. He first referred to the work of Voroschtsov, who pointed out that sodium hydrogen sulphite reacted with azo colours giving rise to a bisulphite of the colour with a general trend towards a less intense colouration. A. T. King had shown that the reaction only proceeded readily when the solutions employed were slightly on the alkaline side of $NaHSO_3$. The ordinary stoving test on dyed patterns does not therefore give a true picture of the fastness of a dyeing to sulphur dioxide in all possible forms. Modified SO_2 tests due to Mr. King and the Geigy Colour Co. were described. This much explanation had been necessary to indicate how slightly alkaline goods exposed to air containing SO_2 might go on absorbing SO_2 until a point was reached where the azo-sulphite formation proceeded and a colour fault arose. Common and uncommon causes of sulphite faults were described by the lecturer and examples shown in illustration. Tests to ascertain the presence of sulphite in wrapping papers, and in silk, cotton, and fibres which themselves do not naturally contain sulphur were detailed. A brief reference was next made to the more recent work done on the action of active sulphites in which it had been shown that not only were azo-sulphites formed but that complete reduction of the azo-molecule could be brought about. This necessitated the use of a still further test, sulphite test No. 5, and this was described by Mr. Goodall, who also referred to the action of active sulphite on other classes of colours beside azo-colours. He next pointed out that if only a small proportion of the dyestuff on any pattern is converted to azo-sulphite the pattern will fade quicker than it should do and that such conditions might arise from the naturally-occurring sulphur in wool.

Mr. Goodall was heartily thanked for his lecture.

NOTES AND NOTICES

Coming-of-Age Celebrations.

Next year, the Textile Institute will attain its majority. The Council has already discussed the matter of suitable celebrations of the completion of twenty-one years of activity of the institution and appointed a committee to make recommendations as to the scope and character of the celebrations proceedings to be undertaken. The Members of Council, members of the various committees, and members generally are asked to make special note of the event and in connection

therewith to assist in promoting the most widespread interest possible. It is intended that the proceedings shall represent the most important Institute endeavour yet attempted. Tentative recommendations have already been arrived at. It is proposed that the proceedings shall occupy two clear days at Manchester, in the latter part of April or early in May 1931, on selected dates coming within the three weeks subsequent to 20th April, and preferably on the Wednesday and Thursday, with an opening Reception on the Tuesday evening. A banquet is suggested for the Wednesday evening, with invitations to representatives of various bodies. On both mornings it is proposed to provide facilities for the contribution of special papers including the Mather Lecture, whilst the afternoons will be devoted to visits of industrial interest or other excursions. At this stage, it is not possible to offer further information as to the recommendations and suggestions, but the Committee desires to stress so far as members generally are concerned, not only the exceptional importance of the occasion but the extreme desirability that complete and outstanding success, with lasting benefit to the Institute, may be achieved by the endeavour.

Proposed Visit to Lyons District

It has been suggested by one or two members of the Institute that a visit of members might be arranged to the Lyons district of France. When placed before certain French manufacturers, the proposal of a visit was most favourably received and immediate offers were made of facilities to visit works and mills. The Council of the Institute considered the matter at its last meeting and it was decided to proceed in the first instance by publication of a note in the *Journal*. It was thought that attendance might take place in association with the next Lyons Fair, which will be held early in 1931, but in view of the fact that at this time accommodation is likely to be limited, the Council agreed that the visit might be arranged either at the time mentioned or in the early autumn of the present year. It was finally decided to place the matter before members in this way. The Council would be greatly assisted in arriving at a useful decision on the project if interested members would communicate with the General Secretary, indicating not only their willingness to participate but their views as to a suitable time for the event.

REVIEWS

Abstract Design. A Practical Manual on the Making of Patterns for the Use of Students, Teachers, Designers, and Craftsmen. By Amor Fenn. Published by J. T. Batsford, London (12s. 6d. nett).

This book does not clear up the meaning of the term "abstract design" as its examples range from the simplest geometric forms to the most elaborate cretonne pattern of its coloured frontispiece based on the lively idea of a fairground. The frontispiece has no connection with the subject of the book. Its theme is not new as it was seen some years ago in a cretonne design and it would have formed a more interesting example had sufficient been shown to indicate how the designer had overcome the difficulties of repetition. The body of the book does not introduce anything new in the basis of pattern nor does it indicate any new or personal variations on old themes. It simply indicates the common-sense approach to pattern design beginning with purely geometric construction with some possible variations in arrangement of geometric units, followed by the introduction of simple ornamental forms. Eighty-six pages and 242 illustrations are devoted to the treatment of borders. The middle portion, 85 pages and 120 illustrations, deals with all-over patterns, followed up with special reference to textiles, and there is a short and very inadequate chapter on nature study and treatment. Information about the application of pattern to process is not included. The introductory chapter on implements and their use is perhaps for the young designer the most useful because it teaches how to set about geometric construction in a business-like manner, emphasising the proper uses

and the proper keeping of drawing instruments, the too frequent neglect of which so often leads to disaster in the clear, precise expression of a working design. The form, however, called an ellipse in the text is not a true ellipse. The subtle form of a true ellipse is not formed from arcs of circles, and this should have been made clear. The merit of the book is in its bringing together a collection of examples of the geometric and ornamental bases of traditional design which previously were to be found scattered in various publications.

R.A.D.

Le Tissage de la Soie Artificielle. By Paul Luc. Published by L'Edition Textile, Paris (594 pp., 331 figs.).

It can be said at once that this is a good book; it is up-to-date, complete—as far as a book may be—and accurate. It contains much more than its main title would suggest, indeed, only five pages are devoted to weaving proper; most of the book is devoted to pre-loom processes and there is even a short section on spinning. After a very brief account of the manufacture of the various types of rayon, of their properties and testing, the author proceeds to give a very complete account of the sizing of rayon yarns. Here he follows French practice and devotes a great deal of his space to hank sizing, though beam and bobbin-to-bobbin processes are not neglected. The account of the newer rayon sizes with linseed and other oils as base—Boyeux size is a typical example—is possibly the most complete yet published in a text book and contains many mixings taken direct from the patent literature (the opportunity may here be taken to correct a misprint on p. 210, para. 2, where "Resinate de calcium . . . . 2" should read "Resinate de calcium . . . . 20"). The next section is devoted to winding for weft and is followed by an account of the preparation of yarn for warp. A short section on weaving proper is followed by one on the adjustment of cotton machinery for dealing with rayon. Common weaving faults are then discussed and methods of washing and dry cleaning rayon fabrics are briefly considered. The book concludes with a chapter on staple fibre and a very full bibliography. This work is eminently readable, the style is simple and should offer little difficulty even to readers whose acquaintance with the French language is only moderate, the printing is adequate and the illustrations, though not good, are of fair quality. It is a very good account of the manufacture of rayon fabrics and is the more valuable as it probably represents current French practice without neglecting the methods employed in other countries.

H.H.

High Drafting in Cotton Spinning. By Charles Barnshaw. Published by Ernest Benn Limited, London, 1930 (price 21s.).

The author in his preface to the work modestly states that the main object of the book has been to deal with high draft arrangements and also that he has found it necessary to refer to the character of the raw material and the preliminary operations which affect drawing, and therefore proceeds in a very full and logical manner to place before the reader not only high draft principles, but a sound reasoning of the principles of cotton spinning which are so vital to all forms of drawing.

He mentions also that "little has been written on the subject of drawing though it is one of the most important operations in cotton spinning," which is certainly true and as regards its importance it is daily proved that good cotton when in yarn state has been degraded by inferior drawing conditions and good drawing can and does appreciate the qualities of both poor and good material.

The references made to the raw material are extremely interesting and have fully covered the points of importance to good yarn production and have been examined from the basis of the spinning capacity of the cotton. Special stress is made upon staple length and thickness, and unquestionably the latter factor does not receive the consideration in spinning that the author would like, and is quite justified in hoping for in the future. He points out that we rigidly estimate fibre length for counts and yet omit serious consideration of thickness, which is certainly the case.

His deductions for yarn breaking load in relation to fibre length and slippage of fibres when under strain are both interesting and accurate, though he could

have included, with advantage, consideration of relative fibre tension controlled by drafting efficiency at this juncture, even though it is not a characteristic of the raw material.

The prevailing condition as regards cotton fibre is that when the fibres of comparative growths are coarser the "staple length" is usually less and therefore in connection with the statement on page 13 that wider roller settings would be necessary for coarser fibres this can only be accepted as having relation to fibres of the same length which were finer.

In connection with the fibre length diagram given the profile does not quite follow that generally found by commercial methods of examining raw cottons as the sudden rise for the longest fibres is more uncommon than general and must therefore be taken as approximate only.

In the first chapter the author indicates that more exact information of raw material is desirable and less of an assumed nature which would unquestionably give more economical and better yarns if in existence.

The section dealing with mixing and blending is thorough and mention is made to the effect that the best system of deciding upon correct mixing or blending is to pass samples through to yarn state, which one finds is done in very many instances, before commercial mixings are laid down for yarn production, but good can only be the outcome of extending the practice.

In this section the intention appears to be to convince the reader as to the undoubted benefits to be obtained by carefully examining the material which has been mixed or blended at all stages of production, as cheaper types of cotton may possibly in the end produce yarns or cloths more costly than better types of raw material at higher prices.

Under the heading of pre-drawing processes very sound consideration is given regarding the mixing value of the cotton card, that is for proper distribution of material as distinct from proportion, which is very vital to good work in drawing. Excellent contentions are raised as regards the over-estimation of the value of doubling and drafting for mixing distribution and the author is justified in trying to stress that most efficient mixing of cotton in yarn state will be achieved by mixing prior to carding.

In connection with parallelism and uniformity the claim is made for the beneficial low draft at the first head of drawing to act as a preparing draft. This is often introduced and is sound and can be arranged for correct ratio of machine production, though in other cases equal drafts in all heads of drawing, other conditions varying, are adopted which as is shown will probably not be to the good of drawing and uniformity.

At this point he now touches on the fringe of the defects of ordinary roller systems in stating that the best drafting can only be obtained by equal length and thickness of fibres which have caused the introduction of more control systems of drawing with material variability and rightly stresses the desirability of proper examination or testing of drawn slivers for short linear irregularities in addition to counts.

The explanations relating to the effects of twist and double roving on drawing are clearly given, particularly as regards the drawing of twisted and untwisted material, and emphasis is laid on the necessity of increasing the efficiency of winding on and off bobbins in order that twist in material used may always be at a minimum for drafting efficiency and economical productions as twist is beneficial to a degree for drafting; the amount is, however, usually less than that required for the operation of feeding uniformly. The claim that "thinner portions of material will be harder twisted portions and cause increased resistance to drawing and in the subsequent machine tend to accentuate the fault existing" is hardly clear unless it means that a thinner may tend to become a thicker fault subsequently, as the place less twisted which is considered to be thicker will pull out easier and may have a slight levelling tendency, to a degree, in drawing.

The information given as regards defects due to stretching in winding by considering tape width of material delivered from speed frames, particularly the slubber, is very good, but if extreme care is not exercised in using the funnel guide suggested, to avoid spreading, irregularities will be increased in practice by drag on the material passing forward, which may mean modifications to material, detrimental to drafting and uniformity.

The references made to single and double roving feeds in relation to drafting are well worth the serious consideration of all spinners and students.

The basis of setting draft rollers is well conceived and much valuable information can be obtained with reference to the actual as compared to the theoretical nipping points and distances of two pairs of rollers, thickness of material, fibre thickness, natural twist, amount of draft, speed of drafting, condition of rollers and tension in front of delivery rollers.

In connection with Diagram 2 the front rollers are shown to be delivering 75 fibres for a 40s yarn, which should be taken as only approximate, and a figure to illustrate the example, as two different authorities have given averages from numbers of tests as 100 and 120 fibres in the cross section of a 40s yarn, but the number of fibres varies considerably in various parts of such yarns as produced from various cottons.

The reference to control length of roller settings is of considerable interest, while the fundamental difficulty of setting rollers with fixed centres to what is known as "staple length," which is variable to different degrees, is dealt with to advantage.

Diagram 3 indicates a very interesing diagrammatic method of showing the necessity of changing the settings of rollers for drawing cottons of similar average staple length, yet with varying degrees of irregularity.

More distinct reference to high draft methods is made in connection with the section dealing with control rollers and points of control where special systems are explained with reference to settings inside staple length. The statement is made that the Trumbach roller is a steel roller but this is not always the case, as other metals can be and are used. In connection with the C.S.L. roller it is explained that the bottom fluted roller is always made with the grooves the full width for driving the top roller and it is pointed out that this can be considered a slight disadvantage in the removal of bottom roller caps, but the reviewer assumes caps is a misprint for laps.

In the chapter relating to rollers in pairs, three-line system and four-line system, it is shown that there are standards of high drafting and principles are explained whereby it is possible to obtain the best results either from normal or high draft systems. Reference is made to the beneficial effects of the back line of rollers in the three-line system and indicates fully their intended use.

Consideration and comparison is made of the differences used for setting the three-line system of rollers for fine and coarse or long and short stapled cottons with staple variations.

Under the four-line system the advantages of the additional controlling point are considered, particularly in short and irregular stapled cottons and for heavy weights of material to be drawn, and stress is laid on the fact that in connection with these systems, quite as much consideration must be given to all details of settings and roller weights according to material to be worked as for any other system of drawing.

The subjects of roller planes and settings have been thoroughly treated and this section is well worthy of consideration by spinners and machinists who are adapting machines from ordinary to high draft methods as in instances one finds the prevalent idea to be simply that of adding an additional line of rollers for high drafting which is totally wrong and useless, unless roller planes and weights are considered. Weight efficiency is also considered in relation to angle of rollers. In connection with the double-grips back top roller system the good points of the system are enumerated.

Consideration is next given to single and double tape arrangements for high drafting, the former being dealt with in connection with the Le Blan Roth and Vanni systems. In both systems the control points and pressure contact receive full consideration.

Referring to the double tape arrangement of Casablanca as probably the pioneer of high drafting systems, the author states that "it possibly possesses greater capacity for efficient control of widely varying length of fibre than any other type" and there is no doubt that the claims made for this system of high drafting can be justified.

Under the heading of "break draft" the efficiency of feeding, namely roving tension, is considered in relation to break draft and the effects of twist in ordinary

and high drafting systems and its relation to economical productions. The differences between break draft and tension draft are explained as well as their relation to possible drafting irregularities.

The beneficial features of the Inter Roving frame receive treatment, though as explained its principles are not essentially those of high draft, but it attempts to eliminate irregularities and reduce spinning costs. German spinners are at the present time working on a similar principle for spinning low counts where they are using material from the draw frames and a condenser and passing it directly to the ring frame.

The cost and quality of yarn with reference to high draft are considered. An analysis of high draft from the factors of slightly reduced cost, slightly finer yarn, and slightly more uniform yarn is made. Quantities and effects of distribution of machines for high draft are considered and comparisons made upon the basis of (*a*) normal drafts, (*b*) normal number of machines (yarn passage), but heavier material at each stage, and (*c*) one set of frames omitted. The comparison is dealt with from the view point of yarn irregularities and drafting range. For satisfaction too much should not be expected in the way of finer yarns as it is easily possible to neutralise all the advantages of high drafts if reason and care are not exercised in this direction.

Finally reference is made to the effect that any changes from ordinary to high draft must be skilfully carried out for best results, and as regards the best type this must be decided with the conditions required as a whole and based on practical tests.

As regards the subject matter in the book it is well set out in proper sequence, which is a desirable feature of technical literature, which is not always found in textile publications, and can be appreciated to the full in this work. The author is to be complimented on his excellent work, which is well expressed, clear, easy to understand, and admirably illustrated. It is an invaluable book for all who are interested in high draft systems and cotton spinning generally. H.B.

GENERAL ITEMS AND REPORTS

Federation of Textile Societies and Kindred Organisations

Third Annual Meeting at Rochdale, April 1930.

By invitation of the Rochdale Cotton Spinning Mutual Improvement Society, and with the co-operation of the Rochdale Textile Society and the British Association of Managers of Textile Works, the third Annual Meeting of the Federation was held at Rochdale, on Saturday, 26th April 1930. The programme for the meeting commenced with a visit to the Dunlop Cotton Mills, at Sudden, Rochdale, where some 60 delegates were conducted over the mills by members of the staff under the direction of Mr. T. E. Mitchell, Assistant Manager. This was followed by an inspection of the rooms and equipment of the Rochdale Cotton Spinning Mutual Improvement Society, at Barlow Street. Luncheon was taken at the Flying Horse Hotel by invitation of the British Association of Managers of Textile Works, and was presided over by Mr. Frank Wright, President of the Association. On the proposal of Mr. J. T. Stokes, seconded by Mr. N. Collinson, a hearty vote of thanks was accorded to the Association for their hospitality as hosts. After luncheon, the delegates held the Annual Meeting at the hotel, and subsequently adjourned to the Rochdale Technical School for the delivery of papers. The Conference was welcomed and declared open by Councillor J. T. Dawson, Mayor of Rochdale, who was thanked for his services, on the proposal of Mr. F. Wright, seconded by Mr. N. Collinson. The following papers were delivered—"Theory *versus* Practice," by W. J. Ellison; "The Modern Ring Frame," by G. W. Walton; "Machinery used in the Manufacture of Fancy Woollen Fabrics," by L. B. Mitchell; and "The Preparation of Leather for, and the Manufacture of, Leather Belting," by R. M. Ormerod. These were followed by an inspection of the Rochdale Technical School.

At the Annual Meeting, Mr. J. T. Stokes (Leicester), retiring Chairman. moved the election of Mr. Norman Collinson (Batley), as his successor. Mr. Copley seconded and the motion was carried unanimously.

Mr. Collinson suitably acknowledged his election, and called upon Mr. Briggs (Blackburn) to propose a vote of thanks to the retiring Chairman. This was seconded by Mr. E. M. Roberts (Bradford) and carried by acclamation.

Minutes of previous annual meeting (1929), as circulated, were approved. In reading the minutes, Mr. H. L. Robinson, of the Textile Institute, expressed on behalf of the Hon. Secretary-Treasurer, Mr. J. D. Athey, his regret at his inability to attend. The meeting, on the proposal of Mr. Briggs, expressed its sympathy with Mr. Athey and good wishes for a speedy and complete recovery of health.

The Annual Report of the Committee of Management was presented. The report stated that at 31st December last there were 34 organisations in membership of the Federation as compared with 31 at the termination of 1928—a position which the Committee regards as highly satisfactory. The advance towards effective co-operation in the whole Textile Society movement was meeting with increased appreciation, and pursuit of the policy of holding the annual gatherings at industrial centres concerned with various branches of activity in textile production was proving of decided interest and influencing a greater breadth of outlook towards problems of the industry on the part of all who participate. The Committee recognised with satisfaction the generous manner in which many textile firms and authorities of technical training instutntions in the various centres visited had granted privileges of inspection and assisted in the provision of information in the form of papers at the Federation conference. Following the practice, a meeting of representatives took place at Manchester on the 20th April last for the consideration of lecture syllabuses. Requirements were stated and much useful information was exchanged. The importance of encouraging contributions of papers or lectures on the part of younger members had been repeatedly urged and it was shown that considerable effort had been made in this direction. The Committee hoped that such effort may be maintained. The Committee met on the 23rd November last, when the Chairman, Mr. J. T. Stokes (Leicester) presided and amongst other matters the arrangements for the annual gathering at Rochdale were considered and promoted. With regard to finance, the accounts had been audited by Mr. W. Kershaw, and at the end of 1929 there was a balance in possession of the Secretary-Treasurer of over £6. The expenditure during the year amounted to £1 13s. 5d., almost exclusively in respect of printing, stationery and postages. The Committee acknowledged the assistance of the Textile Institute in regard to accommodation for meetings and providing secretarial service.

The report was adopted.

Nominations for the election of the Committee of Management were next submitted and there being no further nominations the names were put to vote and accepted as follows—Chairman, Norman Collinson; Lancashire—F. Briggs, W. Kershaw, J. Burgess, and R. Entwistle; Yorkshire—E. M. Roberts, G. W. Haigh, and H. Holroyd; Leicester—W. O'Brien; Textile Institute (Lancashire Section)—H. Nisbet; Textile Institute (Yorkshire Section)—A. Saville.

Mr. J. D. Athey was re-elected Hon. Secretary-Treasurer and thanked for his past services.

Mr. W. Kershaw was re-elected Hon. Auditor and also thanked for his services.

Mr. Burgess (Ashton-under-Lyne) proposed, and Mr. Brown (Guild of Calico Printers) seconded, that the best thanks of the Federation be given to the Rochdale Cotton Spinning Mutual Improvement Society, the Rochdale Textile Society, the Dunlop Cotton Mills Ltd., and the Rochdale Technical School, for invitation to delegates on this occasion. The vote was heartily accorded.

It was decided that the next Syllabus meeting take place on Saturday, 24th May, at the Textile Institute, Manchester.

An invitation to the Federation to hold its 1931 Annual Meeting and Conference at Burnley was read and gratefully accepted, the Hon. Secretary being instructed to communicate with the Burnley Textile Society and thank the society for the invitation, the event to take place at Burnley on the first Saturday in May, and arrangements to be made by the Committee of Management.

THE JOURNAL OF THE TEXTILE INSTITUTE

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PROCEEDINGS

Examination in General Textile Technology

An examination in General Textile Technology in connection with applications for the Associateship of the Textile Institute took place at Headquarters, Manchester, and simultaneously at the Municipal College of Technology, Belfast, on Wednesday, 25th June 1930. For the information of members and others interested, the examination paper, in two parts, is recorded as follows—

PART 1 (SECTIONS I AND V OF SYLLABUS)

10 *a.m. to* 1 *p.m.—25th June* 1930

Candidates to answer THREE out of FOUR Questions in each Section of Part 1

Section I—Fibres, and their Production

(1) Make sketches of the appearance under the microscope, both in longitudinal view and transverse section, of the following fibres—normal cotton, immature cotton, mercerised cotton; well retted flax, and insufficiently retted flax; lustre wool, kemps, and shoddy.

(2) What are the sources, properties, and uses of jute, hemp, and ramie ?

(3) The artificial silks at present on the market may be divided into two classes—(*a*) regenerated celluloses, and (*b*) cellulose esters. What is meant by this classification ?

(4) Describe the characteristic differences between—
  (*a*) Sea Island and Indian cottons;
  (*b*) Botany and lustre wools;
  (*c*) Tussah and Italian silks.

Section V—Analysis and Testing of Raw Materials, Yarns, and Fabrics

(1) What tests would you apply—(*a*) to determine the proportion of wool in a wool and cotton mixture; (*b*) to distinguish sulphur black from aniline black on cotton; (*c*) to distinguish between acetate artificial silk and real silk.

(2) Write a short essay on "Skein testing *versus* Single thread testing."

(3) What do you understand by hygroscopicity and how are tests for "condition" carried out ? What is the effect of "condition" on (*a*) the weight of raw material, and (*b*) strength and elongation of yarns?

(4) Describe how you would proceed to investigate one of the following alleged defects—

(*a*) Uneven dyeing in a yarn-mercerised cotton stocking;

(*b*) Loss of tensile strength in a black cotton fabric;

(*c*) Warp stripiness in a worsted gabardine;

(*d*) A blue artificial silk facecloth which shows irregularly distributed bars of a lighter shade in the weft direction.

PART 2 (SECTIONS II, III, AND IV OF SYLLABUS)

2.30 *p.m. to* 5.30 *p.m.—25th June* 1930

Candidates to answer TWO out of THREE Questions in each Section of Part 2

Section II—Conversion of Fibres into Finished Yarns

(1) Explain the principles of spinning yarn on the Flyer, Cap, and Ring frames and also on the Mule. What are the characteristics of the yarn produced in each case ?

(2) Discuss the principal methods adopted for Mixing or Blending similar and differing textile materials in preparation for spinning.

(3) Give some account of the utilisation of staple fibre in the manufacture of yarns.

Section III—Conversion of Yarns into Fabrics, and Fabrics produced by Special Methods

(1) Compare, by means of sketches, the structure of a gauze or leno woven fabric with that of any one type of knitted fabric. Describe the latch and bearded types of knitting needles and explain how the loop is formed by one of them.

(2) Yarns are supplied to manufacturers in various forms: name as many types as you are acquainted with, pointing out to which branch of the industry each form or method lends itself; describe at the same time how each form best meets the manufacturing requirements of any particular fabric.

(3) What are the chief points which would guide you in the selection of yarns for the manufacture of at least two types of fabric (woven or knitted), which you will name?

Section IV—Conversion of Fabrics into Finished Materials.

(1) Describe the most important bleaching agents used in the textile industry, and give a detailed account of a method of applying one of them to a textile fabric.

(2) What classes of dyestuffs would you recommend in the following cases—(*a*) fast stripes in cotton shirtings; (*b*) worsted costume cloths; (*c*) real silk crepe de chines?

(3) Discuss the factor of Temperature in the practical finishing processes applied to wool and cotton fabrics.

London Section

Meeting at Messrs. Waring & Gillow's Hall on Wednesday, 5th March 1930;
Mr. G. H. Wynn in the chair.

HISTORY OF BRITISH CARPET MANUFACTURE

The lecturer was Mr. S. S. Wyer, who, having been introduced by the Chairman, said he proposed to exhibit a film showing the processes of carpet manufacture and, in order to make the matter clearer, he had had prepared examples of the most important materials used, and these were on exhibition. Before showing the film he gave a brief history of carpet manufacture in England. It was one of the oldest industries in Great Britain, but its introduction into Europe was probably due to the Moors. Instances of carpets of great age and still in existence were given, and evidence as to the incidence of carpet weaving in various parts of this country. In 1701 the carpet weavers of Wilton and Axminster received a charter from William III. The making of loop-pile or Brussels carpets was introduced by the Earls of Pembroke and Montgomery in 1740. Brussels carpets of the Victorian era had extraordinary length of life—40-50 years were known. The development of the cut-pile or Wilton carpet was next described, and then that of the "Scotch" or Kidderminster carpet. The carpets made by Thomas Moore of Moorfields were then referred to and the part played by the Royal Society of Arts in fostering this industry by monetary aid was indicated. Reference next was made to those inventions of the end of the 18th century—the steam engine, the power loom, and the jacquard—which had so much influence in the textile industries and therefore on the making of carpets. The tapestry process of printing and weaving carpets due to Mr. Whittock of Edinburgh was described. "Chenille" carpets came next under discussion and were ascribed to Mr. Templeton of Glasgow. It was about the time of the Exhibition of 1851 that the problem of weaving carpets by power was solved both by Mr. Collier, of Halifax, and Mr. Bigelow, an American. Since then extraordinary progress had been made in machine-made carpets. In the early nineties the Smith Company of Yonkers dumped vast quantities of "moquette Axminster" carpets into this country. This proved a splendid incentive to the British manufacturer, who had not thought it possible to make such cheap carpets. In concluding this historical outline, Mr. Wyer referred briefly to the work of William Morris, who made hand-tuft carpets, of which he was designer, weaver, and dyer.

Then the lecturer gave a brief explanation of the technical side of carpet manufacture, referring to and describing the samples of materials on view. As the film was shown the lecturer pointed out the characteristic structure and machinery used in the making of the various types of carpets. Those shown included the hand-made Axminster, the Brussels, the Wilton pile, and the Axminster.

Lord Waring, who moved a vote of thanks to Mr. Wyer, said knowledge was power, but in this instance it was closely allied to pleasure as well. He was sure all present would have greater interest in carpets as a result of this lecture. The vote was heartily accorded and Mr. Wyer briefly acknowledged it.

Yorkshire Section

Meeting at Huddersfield, 11th February 1930.

INTERNATIONAL CO-OPERATION IN THE WOOL TEXTILE INDUSTRY

The address, under the above title, was delivered by M. Dubrulle, President of the International Wool Association, who thanked the Institute for the honour of Fellowship recently conferred upon him. Economic co-operation, he said, could be defined as a collective effort towards certain objectives for the common advantage. Even before the war the idea was in evidence, and tentative efforts were being made to secure its advantages. In the main these efforts were of a national character, and attempts at international action were few and timid. To those who live in the immediate present these matters might appear of no moment; others can discern approaching storms which threaten the economic world. The war had made it clear to such persons that real economic stability and peace could only be secured by reasonable and ordered cohesion of international economic interests.

The general needs and advantages of international co-operation, said the speaker, had been dealt with exhaustively by economists of all schools and nations. He proposed to direct attention particularly to the needs of the wool textile trade. The inception of the idea had occurred at the time of a personal visit to Bradford in 1919. Then had been suggested that as the principle of unity of control had won the war, its application in business and the economic sphere appeared equally desirable. Mutual action had resulted and meetings held in Bradford, and in Roubaix and Tourcoing, had finally ended in a more formal meeting in November of 1924 of two British and two French delegates empowered to act in furtherance of the scheme. An agreement, known as the Franco-British Arbitration Agreement, was drawn up and this marked the inauguration, in the lecturer's view, of an era of better understanding.

Subsequently, said M. Dubrulle, other countries came into the scheme, which now embraced Belgium, Germany, Italy, Czechoslovakia, Holland, Poland, and Hungary. Questions considered included the proper packing of raw wool material, the suitable marking of fleeces, and recommendations to sheep-breeders. In natural sequence economic questions, such as the limitation of credits, the unification of wool standards and appellations would receive consideration. Statutes were being drawn up for consideration by a general conference to be held in Paris. As regards technical matters one could anticipate the possible inclusion of wool-producing countries. Their co-operation and concurrence was indispensible in the effective consideration of such matters as he had already referred to.

M. Dubrulle then turned to a number of economic topics, such as values—to be governed solely by the economic laws of supply and demand; regularisation of credits—in connection with which it was desirable to secure unification of selling terms and conditions; commercial intelligence—in which centralisation was desirable; and welfare schemes, which would eventually receive consideration. Their programme, said M. Dubrulle, was pretty full, but there was much unexplored territory in the wool textile sphere; if they were desirous of promoting the interests of their industry industrially and commercially, they must not be faint-hearted in the good work.

In the second part of his address, M. Dubrulle devoted himself to considerations of general international co-operation and the part to be played therein by representatives of the wool textile industry.

Midlands Section

FORMATION MEETING

A meeting of Institute members and friends in the Midlands area was held at the Loughborough College, Loughborough, on Thursday, 19th June, for the purpose of consideration of a proposal to form a Midlands Section of the Institute, the proposal having already received the sanction of the Council. There was an attendance of about thirty members, and Mr. Frank Nasmith (Chairman of Council) occupied the chair.

Mr. Nasmith welcomed the visitors and said that up to the present time members in the Midlands had been attached to the London Section, which represented largely the distributive side of the industry and was not perhaps specially attractive to members in the Midlands. It had been felt for a long time by certain members in the latter area that there ought to be a separate Section and the Council agreed. If the Section was to be formed, it should be distinctly understood that it was the responsibility of the members to make the movement successful. Whilst the Headquarters would assist, it was desired that Sections should take up a resaonable measure of responsibility and independence. It was in no wise desirable that Sections should become parochial or enter into competition with existing local textile societies. Sections of the Institute should be specially concerned with the advancement of textile technology in relation to branches of industry in their area. It would be necessary to secure the services of an Honorary Secretary, and in this connection considerable assistance could be obtained from Headquarters.

Questions were invited and in reply to questions it was stated that existing membership strength in the area was about eighty.

On the proposal of Mr. J. Barr, seconded by Mr. J. Chamberlain, it was resolved unanimously that a Midlands Section be formed.

It was also decided to appoint a Provisional Committee, consisting of the two members of Council from the district (Mr. T. Morley and Prof. Davis), and seven other members, as follows—Messrs. Barr, Bastard, Bentley, Chamberlain, Walker, Ward, and Wykes.

A hearty vote of thanks was carried to the Loughborough College for facilities and hospitality in providing tea. This motion was proposed by the Chairman and seconded by Mr. W. W. L. Lishman, Hon. Treasurer of the Institute, the latter wishing every success for the new Section.

A vote of thanks to the Chairman ended the meeting.

Subsequently, the Provisional Committee met, when Mr. T. Morley was appointed Chairman.

It was agreed that the Provisional Committee should serve until the time came next year for election in the usual manner.

Mr. J. Chamberlain agreed to accept the Hon. Secretaryship, and Mr. W. Bastard kindly offered assistance.

It was decided that the Provisional Committee meet at Loughborough at 3.15 p.m. on the 10th July to consider programme, and it was further agreed to hold three special meetings during the coming winter at different centres, Headquarters to be asked to suggest lecturers and to send a representative, or the General Secretary, to speak briefly at the meetings on the Institute's work, the meetings to be regarded partly as propaganda efforts.

Scottish Section

Meeting held at the Scottish Woollen Technical College, Galashiels.

COSTING AND PRICING IN LINEN WEAVING

By Andrew R. Geary, A.T.I.

In almost every manufacturing concern it is necessary at the present time to make a distinction between the "cost" and "selling price." It is my intention, therefore, to deal with the subject under two heads, viz.—(1) The minimum figure that may be used without a loss and which, for convenience, we will refer to as "cost"; (2) the figure which, under more normal conditions, one would refer to as the true cost, i.e. showing a reasonable return for the capital and brains put into the business, and which we will term "price."

Excluding for the moment the question of dumping (and one wishes that it could be permanently excluded), cases are not uncommon of two firms, working under similar conditions, quoting, for the same article, prices that vary to an alarming extent. It is realised that many factors may be the reason for this difference, e.g. finance, or rather the lack of it, and a different organisation; but even where there is practically no difference in the financial standing or efficiency of the organisation, one still finds these variations and has to conclude that there is actually no difference except on paper.

How often has one heard the statement "there is no use our entering for this line as Brown, Jones & Robinson are 'specialists.'" If the costing were accurate, however, in many cases it would be found that due to a larger distribution of "overheads," more varied equipment, wider experience, and better organisation, firms were in a better position to quote a lower price than the "specialist." If each type of cloth bears only its own portion of the expenses, then it is reasonable to assume that more business will accrue than by working on the same average figures for all types. The old system of calculating the cost of a plain cloth at three times the weaver's wages, plus the price of the yarn, served its purpose in the years gone by but is no longer serviceable.

My idea of correct costing is to apportion the non-producing or non-manufacturing items of expenditure over the processing departments. This will be more fully explained later on, but the incidental advantages of this system are that if a manufacturer buys his warp on cheeses, or weft on tubes, he not only leaves out the actual wages for winding, but the overhead charges also. If he is making a union or cotton cloth and buys, as is generally the case, his cotton on beams for warp, then he must omit not only the wages for winding and warping but also overhead expenses. Likewise, for an all cotton, and buying the weft on tubes, all the weft winding charges should be excluded.

Raw Material—As a rule the manufacturer buys this in the "green" or "grey" state at a price of so much per bundle (60,000 yards) or per spindle (14,400 yards), less a discount for payment within a given period. After buying, the manufacturer makes his own arrangements for the boiling, bleaching or dyeing, if any of these treatments are necessary. The number of bundles required to make a piece of cloth can be easily and accurately ascertained, and to this the quantity required to cover waste in manufacturing has to be added. The percentage allowance for waste will vary according to the quality and counts of the yarn used, the treatment the yarn has received, the length of "set" or "run" brought round at one time, the skill of the individual worker, and the efficiency of the machinery and organisation. In addition, foreign yarns are often badly handled before reaching here, with the result that there is an excess of waste in the winding. Very often with coarse counts of 20s and under there is a tendency on the part of the spinner to spin heavy and, to keep himself right, give short length, requiring

the manufacturer to allow as much as 7½ per cent. All of this is not a manufacturing waste, but the point is that the manufacturer has to include it in the cost of the yarn. If the count of the yarn is 25s and finer, 3% in warp and 3% in weft should be sufficient for grey yarns, but bleached and dyed yarns will probably require more than either grey or boiled yarns, and tow than line. A fairly accurate estimate of the waste can be found by recording the estimated quantities under the various counts, qualities, and treatments, and comparing these with the actual consumption.

Yarn Treatment—As this is usually done by an outside firm of bleachers, who charge standard rates, the total cost has to be added to the yarn costs.

PROCESSES IN LINEN WEAVING

For the purposes of the present article the processes in linen weaving may be summarised as follows—Yarn Storage; Warp Winding—Warping; Dry Beaming; Dressing, and Weaving—Plain, Fancy, and Damask.

GENERAL NOTES

Depreciation—Would suggest that in the case of old machinery this item should be kept very low and possibly omitted from the cost altogether, as the amount required for upkeep, and which must be taken, will be high as compared with more modern machinery. It might be better to place under "price."

Oil—Used in all machines, and it will be taken for granted that this item is added under the heading of furnishings.

General Expenses—Office expenses; all salaries; feu-duty; rates and taxes; wages and insurance of office staff. Contributions to superannuation fund, charities, trade organisations, research, advertising, workers' canteen, etc. These to be allocated over the following departments—Yarn store, warp winding, weft winding, warping, beaming, dressing, drawing-in, weaving, cloth office, cropping, lapping, storage; and will be found under the heading of "cost," i.e. charges that must be provided.

Workers' Insurances—Includes health, unemployment, and accident (employer's portion of health and unemployment).

Rent of Buildings—If these belong to the occupiers, it is probably best to charge them under "price," but if they belong to others, then the figures will have to be included in "cost."

The rent, or a percentage in the capital value of all the buildings and fittings, to be distributed over the same departments as above (not necessarily in the same proportions). This means that the rent of the particular building includes the proportion of office rent, power buildings, mechanic shop, etc.

Power, Lighting, Heating, and Humidifying—To be included under the "cost" charge and allocated to the same departments as above. It is understood, of course, that the only one of the above to be charged to the yarn store will be "lighting." Similarly "lighting and heating" will be the only part of these burdens to be borne by the drawing-in and cloth storage.

Cost.	Price.
Fuel, oil, and carriage.	
Depreciation of plant and buildings.	
Wages and workers' insurances.	Per cent. on capital value of plant.
Fire insurances.	
Maintenance.	

Mechanic Shop—Similar to above, substituting "materials" for fuel.

Furnishings—Allocated to manufacturing departments.

YARN STORAGE

Cost.	£ s. d.
(1) Prop of general expenses ...	
(2) Storekeeper's wages and insurances	
(3) Yarn carriages	
(4) Artificial lighting	
(5) Maintenance	
(6) Insurance of buildings and stock*	
(7) Depreciation	
Total for one year £	

Price.	£ s. d.
The preceding total plus a percentage on Nos. 1 to 6 ...	
*Say 5% on capital required for yarn purchase	
Prop. of rent	
Total ... ... £	

Cost per bundle—The total for one year divided by the number of bundles used in one year at full production.

Price per bundle—Total for price divided by same number as preceding.

*When abnormal stocks of yarn are held it is usually because a rise in price is anticipated. If the rise comes then the extra charges for interest and insurance will be fully met by the higher price obtained or by being in a position to draw profitable business. If the rise does not materialise, then the extra charge will have to be written off as a loss the same as if stocks or shares were bought with the same object

With reference to the insurance of stock it would be well to include here the yarn stock spread over all departments

WARP WINDING – including Spool Store

Cost.	£ s. d.
(1) Proportion of general expenses	
(2) Foreman and assistants + insurance	
(3) Winders insurances (full staff)	
(4) Eke winders wages + insurances	
(5) Prop. of power, heating, and lighting	
(6) Prop. of mechanic shop expenses	
(7) Furnishings and prop. of expenses	
(8) Insurance of buildings ...	
(9) Insurance of plant and accessories	
(10) Other expenses pertaining...	
(11) Depreciation of machinery	
(12) Depreciation of buildings...	
Total for one year £	

Price.	£ s. d.
The preceding total + 5% on Nos 1 to 10	
Rent of buildings	
Per cent. on capital value of machinery and accessories ...	
Prop of interest on power plant	
Prop. of interest on mechanic shop plant	
Total ... ... £	

$$\text{Cost per bundle of overhead charges} = \frac{\text{Total for one year}}{\text{No. of bundles wound in 1 year with a full staff.}}$$

$$\text{Price per bundle overhead charges} = \frac{\text{Total for one year}}{\text{No. of bundles wound in a year.}}$$

$$\text{Cost per bundle for winding} = \text{Cost per bundle of overheads} + \text{Actual wages per bundle.}$$

$$\text{Price for winding} = \text{Overheads at price} + (\text{wages and } 5\%).$$

WARPING—including Beam Store

COST.	£ s. d.	PRICE.	£ s. d.
(1) Prop. of general expenses...		The preceding total	
(2) Foreman and assistants' wages and insurance ...		5% on Nos. 1 to 9	
(3) Warpers' insurances ...		Rent of buildings	
(4) Prop. of power, heating, and lighting		Per cent. of value of machinery and accessories	
(5) Prop. of mechanic shop expenses		Prop. of interest on power plant	
(6) Furnishings and prop. of expenses		Prop. of interest on mechanic shop plant	
(7) Insurance of buildings ...			
(8) Insurance of machinery and accessories			
(9) Other expenses			
(10) Depreciation of machinery			
(11) Depreciation of buildings...			
Total for one year £		Total ... ... £	

$$\text{Cost per hour per machine} = \frac{\text{Total for one year}}{\text{No. of machines} \times 2{,}400^{*}}$$

*50 weeks of 48 hours = 2,400 hours.

$$\text{Price per hour} = \frac{\text{Total for one year}}{\text{No. of machines} \times 2{,}400.}$$

$$\text{Cost per piece} = \frac{\text{Time taken per sett} \times \text{cost per hour} + \text{actual wages}}{\text{No of pieces in sett.}}$$

$$\text{Price per piece} = \frac{\text{Time per sett} \times \text{price per hour} + 105/100 \text{ wages}}{\text{No. of pieces in sett.}}$$

DRY BEAMING

Same principle as warping.

DRESSING

Similar items fall to be charged as under warping and beaming, but in addition there is the cost of making and ingredients. The ingredients used vary according to the treatment the yarn has previously received, and the finishing process the cloth is to receive. The quantity will also vary according to the weight of yarn, and whether dry spun or wet spun, and treatment. From this it will be understood that figures will have to be arrived at to meet the above variations.

DRAWING-IN AND SLEYING

(Including Beam Storage.)

COST.	£ s. d.	PRICE	£ s. d.
(1) Prop. of general expenses ...		The preceding total	
(2) Foreman and assistants + insurance		5% of Nos 1 to 5	
(3) Drawer-in's insurance ...		Rent of buildings	
(4) Prop. of heating and lighting		Per cent on value of equipment	
(5) Insurance of buildings and equipment			
(6) Depreciation of buildings and equipment			
Total per annum £		Total ... ... £	

$$\text{Cost per hour} = \frac{\text{Total per annum}}{\text{No. of drawers} \times 2{,}400 \text{ hours.}}$$

Dealt with as in cost column + an addition of 5% to actual wages.

$$\text{Cost per cut} = \frac{(\text{Time per beam} \times \text{cost per hour}) + \text{Actual wages}}{\text{Cuts per beam.}}$$

WEFT WINDING

(Including Pirn Store, Storage, and Accessories.)

Similar to warp winding, but if both cops and pirns are used then the expenses will have to be split, each form of winding being dealt with in the same detail. One of the advantages of such a method is being in a position to make an exact comparison of the costs and prices of each of the two systems. One of the first things which will be noticed is that a cop-winding machine will occupy a greater floor space than a pirn-winding machine having the same number of spindles.

PLAIN WEAVING

(Including all excepting Looms with Jacquard Machines.)

If looms are all uniform in width, shedding and picking mechanisms, and box motions, the apportionment of the expenses is comparatively easy, but when they vary in any and all of the above particulars, and when placed here and there between Jacquard looms, more attention requires to be given to the question.

Let us first consider looms of a standard pattern and then proceed as before.

Cost.	£ s. d	Price.	£ s. d.
(1) Prop. of general expenses...		The preceding total + 5% on Nos. 1 to 10	
(2) Foreman and tenters and assistants + insurance ...		Rent of buildings	
(3) Weavers' insurances ...		Per cent. on value of machinery and accessories	
(4) Prop. of power, light, and heat (artificial humidity)		Prop. of interest on power plant	
(5) Prop. of mechanic shop expenses		Prop. of interest on mechanic shop plant	
(6) Furnishings and prop. of expenses			
(7) Annual cost of heddles and reeds			
(8) Insurance of plant and accessories			
(9) Insurance of buildings and fittings			
(10) Other expenses pertaining			
(11) Depreciation of machinery			
(12) Depreciation of buildings...			
Total per annum £		Total ... ... £	

PLAIN WEAVING—Uniform Pattern of Loom

Cost	Price
Cost per hour per loom $= \dfrac{\text{Total for one year}}{\text{No. of looms} \times 2{,}400 \text{ hours}}$	As with cost.
Cost per piece = (Cost per hour × time*) + weavers' wages.	As with cost + 5% on weavers' wages.

*With regard to the time taken it is desirable that the production from each loom should be recorded in such a manner as to be immediately apparent.

PLAIN WEAVING—Varying Widths, but same Standard

Costs made up for each width and cost per hour worked out.	Price made up for each width and worked out.

With regard to the time taken it is obvious that the wider the loom the slower the speed and possibly the production. Generally speaking, the broader the loom the better the yarn and weaver to work the loom.

PLAIN WEAVING—Varying Widths and Mechanisms

The numbers of each taken and approximate costs for each type worked out. When this has been done, the production from each type to be noted.

DAMASK WEAVING

It is most unlikely that there is in existence a damask weaving shed with looms all the same width, or with the same number or type of machine on each, so that in this case many varied factors have to be considered.

The method of allocation proposed is to make up the "cost" and "price" for each different group. Taking the following items—

Cost (25 Nap. Looms 2/4°° m/cs.)	£ s. d.
(1) Prop. of general expenses...	
(2) Prop. of foreman and tenters' wages and insurances...	
(3) Weavers' insurances ...	
(4) Proportion of power, light, and heat	
(5) Proportion of mechanic shop expenses	
(6) Furnishings and prop. of store expenses	
(7) Prop. cost of new designs and cards	
(8) Cost of new reeds (harness and weaving)	
(9) Insurance of 10, 11, 12, 13, 14	
(10) Depreciation of harness (i.e. cost of keeping in repair)	
(11) Depreciation of cards (i.e. cost of keeping in repair)	
(12) Depreciation of looms ...	
(13) Depreciation of machines...	
(14) Depreciation of buildings...	
Total	£

Price.	£ s. d.
The preceding total	
Rent of buildings	
Prop. of interest on power plant	
Prop. of interest on mechanic shop plant	
Per cent. on value of harness	
Per cent. on value of cards ...	
Per cent. on value of looms ...	
Per cent. on value of machines...	
5% on 1 to 9	
Total	£

CLOTH INSPECTION

Cost.	£ s d.
(1) Prop. of general expenses ...	
(2) Cloth inspectors and markers' insurances	
(3) Proportion of heat and light	
(4) Insurance of buildings and fittings	
(5) Clerk and expenses	
(6) Depreciation of buildings and fittings	
Total for one year	£

$$\text{Cost per piece} = \frac{\text{Total}}{\text{No. of pieces}}$$

Note—"The cost per piece" will vary according to the time taken for inspection. A "glass cloth" where the lengths have to be checked, and number of towels counted, will cost more than a plain cloth. Similarly damask cloths cost more than piece goods.

Price.	£ s. d.
The preceding total	
5% on Nos. 1 to 5	
Rent of buildings and equipment	
Total	£

$$\text{Price per piece} = \frac{\text{Total}}{\text{No. of pieces}}$$

Same remarks apply as for "cost."

CROPPING

Cost.	£ s. d.	Price.	£ s. d.
(1) Prop. of general expenses...		The preceding total	
(2) Foreman and assistants + insurance		5% on Nos. 1 to 8	
(3) Prop. of power, heating, and lighting		Rent of buildings	
(4) Prop. of mechanic shop expenses		Per cent. on capital value of machinery, etc.	
(5) Furnishings and prop of expenses		Prop. of interest on power plant	
(6) Insurance of plant and accessories		Prop. of interest on mechanic shop plant	
(7) Insurance of plant and buildings			
(8) Other expenses			
(9) Depreciation of machinery			
(10) Depreciation of buildings...			
Total for one year £		Total ... ... £	

$$\text{Cost per hour} = \frac{\text{Total}}{\text{No. of machines.}}$$

Cost per piece = Cost per hour × time.

Price as with cost.

Narrow goods can be run through two or three at a time.

LAPPING (FOLDING AND MEASURING)

Similar items as for cropping to be charged, but as the machine usually takes one piece at a time the totals may be divided by the number of pieces without working out the cost on a time basis.

CLOTH STORAGE AND DESPATCH

Items of expenditure, etc., divided by number of pieces woven in one year gives "cost or price" per piece. Strictly speaking, the time a piece is stored should be charged for, but normally all that is required is the time required between consignments.

DAMAGES

To the "costs" of working and the cost of material an addition has to be made for damages.

The proposals which have been outlined cover the manufacture in a weaving factory where the goods are made and sold to a warehouseman. If the business of a warehouseman is carried out in the firm the same principles can be applied to the costing and pricing.

NOTES AND NOTICES

Employment Register

In connection with the Employment Register kept at the Institute with a view to the introduction of suitable candidates for employment vacancies, the following announcements relate to members who have filed particulars of their qualifications and experience, and who seek employment. Employers may obtain further particulars by application to the General Secretary—

40—Seeks post as Worsted Spinning Manager or Technical Assistant. Age 36; over nine years of experience; winner of several scholarships for technical training; experience in teaching and lecturing.

41—Holder of M.Sc. Tech. and F.T.I., with teaching and industrial experience (machinery section); also experience abroad.

42—Worsted Spinning Overlooker, 24 years, seeks post as Spinning Mill Manager; full technological certificate of City and Guilds, and several evening course certificates.

Warner Memorial Medal

In recognition of the valuable services devoted to the Institute by the late Sir Frank Warner, of London, the Council has decided to establish a Warner Memorial Medal to be awarded at intervals of from two to five years in respect of published original investigation in textile technology. Sir Frank Warner served as Chairman of Council for several years and became President, holding the office for three years, at a time when his great energy and influence were of extreme importance in relation to the progress of the organisation. Although his predecessor in the presidential office, the late Sir William Mather, was responsible for the initiation of the Foundation Fund, it was due to the later endeavours and generosity of Sir Frank Warner that the Fund was substantially augmented and developed, thus allowing for a definite forward movement in regard to the Institute activities generally. In deciding that the memorial take the form of a Medal, the Council followed the practice in this connection of many similar bodies, information secured showing an overwhelming record of action in this direction with awards almost invariably associated with published work.

Institute Examination

The Examination in General Textile Technology relating to applications for the Associateship of the Institute, and held on the 25th June, at Manchester and Belfast, simultaneously, produced a record number of candidates—17 as against 12 at the last previous examination. The conduct of the examination at centres other than that of the Institute Headquarters, according to the *locale* of candidates, has so far been rendered possible by kind co-operation on the part of the authorities of technical colleges, and the Selection Committee of the Institute is grateful for facilities generously granted and offered. So far, local arrangements have been confined to Glasgow and Belfast, but in the event of a justifiably sufficient number of candidates or of the incidence of inconvenience of distance, other centres may yet be selected, and it is hoped that similar facilities may be available.

Institute Annual Competitions

Entries for the current year's competitions of the Institute in respect of the design and structure of woven fabrics, novel structure of fabrics, and special yarns, are now to hand. The total number is 57 as against 55 in the previous year. For the major competition, in connection with the Crompton Memorial Fund, there are 13 entries as compared with 11 last year; 6 entries in the yarns

section, as against 7; 14 for the special fabric, as against 22; and, for the prize for special students, 24 in comparison with 15 for the previous year. The Competitions Committee has again given careful consideration to the matter of revision of the whole prize scheme and the conditions of competition, and decided, in view of the somewhat drastic amendments effected a year ago, that the prospectus for the coming year's competitions shall not be materially altered. It was generally felt that a sufficiently lengthy period of operation of the amended conditions should be experienced in order that a really useful test as to their suitability and effectiveness might be secured.

A World Tour

Mr. and Mrs. John Crompton have returned to their home in Ansdell, Lancashire, fit and well, after an absence of several months spent on a world tour. Mr. Crompton made early call at the Institute Headquarters on his return and presented the Institute with an exquisite specimen of old Chinese silk damask. The specimen is of extremely fine texture and graceful ornamentation, produced by multiple-coloured wefts on a black ground. Bold contrast in design is secured without sacrifice in durability of the material. The structure of the fabric is such that all the wefts, back and front, are securely bound and long floats avoided. The specimen forms an interesting addition to the Institute's collection.

Textile Institute Diplomas

Elections to Fellowship and Associateship have been completed as follows since the appearance of the previous list (May issue of this *Journal*).

FELLOWSHIP

PEIRCE, Frederick Thomas (Manchester).
BUTTERWORTH, Ernest (Co. Antrim, Ireland).

ASSOCIATESHIP

ASHWORTH, John (Nelson).

Institute Membership

At the June meeting of the Council, the following were elected to Membership of the Institute—D. Baird, jun., "Mossbank," 110 Hamilton Road, Rutherglen, Scotland (Textile Manufacturer, Asst. Manager); R. N. Baird, "Mossbank," 110 Hamilton Road, Rutherglen, Scotland (Textile Manufacturer, Asst. Manager); R. E. A. Kirkwood, "Pellipar," Silverwood, Lurgan, N. Ireland (Technical Asst.); Arthur Lund, 5 Park View Terrace, Heaton, Bradford (Textile Designer); J. G. Smith, "The Ranch," Stanhill Lane, Oswaldtwistle, Lancs.; A. W. Stevenson, 8 Chestnut Avenue, Headingley, Leeds (Physicist); P. E. Trent, The Cathkin Laundry (London) Ltd., Putney Bridge Road, London, S.W.15 (Chemist); Thos. Wareing, Grecian Emery Works, Rochdale (Card Grinding Machinists).

REVIEWS

The *Penicillia*. By Charles Thom. Ballière, Tindall & Cox, London. (Pp. xiv+644, with 99 figures in the text; 45/- net.)

The genus *Penicillium* includes some of the most widely distributed and some of the most destructive of all mould fungi. A number of species attack textiles, particularly cotton goods, and share with the *Aspergilli* the responsibility for well over 90% of the mildew damage sustained by the Lancashire cotton trade. The number of species in the genus is very large and the justification for a book such as the present one lies in the fact that, to use Thom's own words, "Alive and actively growing, they have individuality as pronounced as their capabilities for evil," and therefore some means of identification is absolutely necessary if we are to be able to understand their reactions and to combat their ravages. There have been a number of previous attempts to systematise the genus, but the basis of classification has always been more or less unsatisfactory, and any mycologist working with a collection of *Penicillia* has been fortunate if he could identify with any feeling of certainty even half of his species, using all the literature published up to the present.

The impression gained by a first perusal of Thom's book is that *Penicillium* has not been straightened out with the same degree of success as was *Aspergillus* by Thom and Church in 1926. There is seldom the same definite dictum, "accepted" or "to be dropped," there is no list of accepted species, and even the confines of the genus are only provisionally fixed. *Aspergillus* is, however, a much easier genus than *Penicillium*. The most outstanding difference is that in the former there is a great range of characteristic colour and the colours are comparatively stable, whereas in *Penicillium* the colony colours are quite unstable throughout the growing period and, with few exceptions, the different species are all some shade of green, at least during the earlier stages of growth. Whereas, therefore, colour was made the basis for primary division into groups of the *Aspergilli*, it is used for classifying the *Penicillia* only when more stable features have been given due consideration. In this case the mode of branching of the fruiting organs is made the basis of the division into groups, there being four main groups, defined according as the "penicillus" is monoverticillate, asymmetric, symmetrically biverticillate, or polyverticillate. Group sections are defined variously, according to convenience. The Monoverticillata are classified as "Stricta" and "Ramigena," whilst the large group of Asymmetrica is subdivided mainly according to colony texture, it being pointed out that this is closely related to the habit of growth as revealed by a study of vertical-radial sections through the growing colony. The Biverticillata-symmetrica are separated into sections according as they are ascogenous, coremiform, funiculose, chromogenic or none of these, whilst the Polyverticillata form a small group needing no further sub-division. Sub-sections are defined from more arbitrary characteristics, the aim being to reduce the large number of species to groups of manageable size, even when what may be regarded as real relationships are absent.

One of the most valuable features of Thom's work is that he has studied, not a limited number of isolated strains such as has formed the material for some previous studies of the genus, but literally thousands of cultures. He has thus been able to show, as earlier with *Aspergillus*, that certain common species, such as *P. chrysogenum* and the apple-rot organism *P. expansum*, exhibit a certain amount of variation in colony colours, size, and markings of parts of the penicillus and in biochemical activities. If only the extremes from such a series of related forms be brought together, there seems to be justification for regarding them as separate species, whereas when the whole series is studied the differences between successive members are seen to be almost imperceptible, and no mycologist could hope to define one particular strain in terms which would ensure its recognition, as distinct from the related strains, by any other worker.

The general arrangement of the book is very similar to that which was adopted in "The *Aspergilli*." The first chapter is a characterisation of the genus in general terms, followed by a "History of *Penicillium*." Then comes an account of various culture collections and of the sources of the author's own material. Chapter IV is a discussion of various generic names under which *Penicillia* have been described, or which have been dropped by previous authors

and included in *Penicillium*. Then follow two extremely useful chapters on cultural methods and on methods of observation and description. In this and in other places in the book Thom particularly emphasises the necessity for observation of living cultures under the microscope, a means of acquiring valuable diagnostic data which has apparently been neglected by other workers on the genus. The next four chapters deal respectively with "Physiological Activities," "Biochemistry," "Distribution and Significance in Nature and Industry," and with the pathogenic *Penicillia*. These, whilst necessarily limited in scope in a book which is primarily taxonomic, give a sufficiently useful picture of the manifold activities of the moulds. Chapter XI traces the position of *Penicillium* in the great class *Fungi Imperfecti*, characterises four related genera which are provisionally accepted, *Penicillium* proper, *Gliocladium*, *Scopulariopsis*, and *Paecilomyces*, and gives a general key to the various groups and sections which are discussed in detail in the following fifteen chapters. There is no attempt to give a general key to the whole number of individual species, its place being taken by group and sectional keys at the beginnings of the appropriate chapters. With regard to the genera other than *Penicillium*, it is interesting to note that Thom now transfers to these a number of species previously described by him as *Penicillia*, such as *P. roseum* to *Gliocladium*, *P. brevicaule* and its allies to *Scopulariopsis*, and *P. divaricatum* to *Paecilomyces*. Whether the proposed genera are finally retained or disappear the excellent descriptions of these anomalous forms should clear away much misunderstanding.

In the last chapter of the book Thom states his conception of a species (a section which should be read by all biochemists who are interested in the so-called *Penicillium glaucum*), then summarises the requirements for identification of *Penicillia*, and gives a number of short keys based on certain conspicuous characters and leading to the more detailed sectional keys. An extensive bibliography, which might have been somewhat increased in value by the use of reference numbers throughout the book, completes the volume.

There are a number of misprints scattered through the book, but few of these are likely to cause the least misunderstanding and they therefore need not be enumerated. The illustrations are well chosen and to the point. There are very few of the highly magnified camera lucida drawings which adorn most of the previous monographs on *Penicillium*. Instead there are sketches, at low magnification, of growth habit, illustrating one of the principal methods used for subdividing the great groups of species. The diagnoses of individual species, or at least of those which Thom has actually handled in culture, are given with a wealth of relevant detail which should serve as a model to future authors.

As the author himself states, the identification of species is still far from being easy. There are still many gaps in our knowledge of these fungi; we know too little about real affinities within the genus—there is, for example, a promising field of work, as yet scarcely explored, regarding heterothallism amongst the ascogenous *Penicillia*—and it is to be hoped that this monograph is by no means the last word on the subject. It is, however, easily the most valuable work which has yet appeared and we can only be grateful that the author has not delayed publication because of the imperfections of which he himself is only too conscious.

The book is one not to be read; but to be in daily use in the culture laboratory, and, even at the rather high price, it is a volume which no serious student of the saprophytic moulds can afford to be without. G.S.

Trade Organisation: Cotton Spinning, Vol. I; Illustrative Forms, Vol. II. F. Greenhalgh. Published by the Author at 68 Albert Road West, Bolton. (Vol. I, 276 pages; Vol. II, 14 tables. Five guineas.)

The time when management in the cotton industry is almost completely overwhelmed, by the extra demands made by chronic depression on their capacity and energy, is not perhaps the most propitious for the publication of such a work as this of Mr. Greenhalgh. Scientific costings methods are best studied and adapted in an atmosphere of calm by minds free from tension and anxiety, with leisure enough for solid reading, and under conditions of security that permit an undivided devotion to internal mill organisation. The general run of mill directors and managers is not so fortunate as to satisfy any one of these requirements.

Yet it is just to urge at this emergency, as Mr. Greenhalgh rightly argues, that scientific costings would prove most helpful and are most necessary.

In these untoward circumstances, a recommendation either to adopt, or to adapt, this or that costings system should perhaps be accompanied by a full appreciation of the doubts and difficulties that harassed mill managers experience in this connection. They may quite reasonably advert to remedies offered by other experts, each of whom has imagined himself to possess the panacea to trade depression. In the past decade many trails have been blazed, purporting to lead to trade recovery, which, when followed up, have either been found to lead nowhere or have led eventually to insurmountable obstacles. After many false starts the spinners find themselves further away than ever from security, and they may justly suspect that scientific costings will do them no better service.

They may point to the existing disparity between their costs and selling prices and ask whether scientific costings will remove that disparity. The answer is that scientific costings will make only a relatively small difference; but that the difference is worth securing. The position is roughly as follows—Whereas scientific costings will detect economies worth perhaps $\frac{1}{8}$d. to $\frac{1}{4}$d. a lb., Lancashire yarns, by the time they reach the buyers of finished cloth, are either 2d. a lb. too dear or sold at that loss—a loss that other interests force upon the spinners. Economies worth $1\frac{3}{4}$d. a lb. must be sought in other directions.

At this the spinners may reasonably exclaim, "What is the use of scientific costings when everything points to inevitable bankruptcy?" The reply is that scientific costings is only one of a number of lines of attack along which simultaneous advances should be made That its adoption, by spinners, would disarm hostile critics of one of their most potent weapons is an advantage deserving emphasis. The device of seizing at every suggested fault in management (*i.e.* faults common to all enterprise whether prosperous or not) as a means of distracting attention from the more fundamental causes of depression, is shamelessly exploited by the vested interests, who, themselves responsible in a large measure for depressed industry, are anxious to attribute all the blame to management. Besides, $\frac{1}{8}$d. a lb. economy on a 60,000 lb. weekly production means £1,575 a year. It will make a vast difference to surviving firms, when, if ever, the industry secures justice for itself, if their capital resources are not depleted or their debts not increased by that amount.

"Why," it may then be asked, "do our old costings methods no longer meet requirements as they once obviously did?" The answer is that, in better times, the range of counts spun was narrower than present exigencies impose on the mills; that there was little or no complication through short-time running and idle machinery, that, with prices and margins more stable, costs were more subject to accurate estimation; that prices were less subject to the factor of selling below cost; and that the assurance of profit left a greater margin for error. With all these circumstances changed, it is no longer possible to guess with fair accuracy; the concensus of spinners' ideas on the relative values of yarns is more often than not wide of the mark; and hidden differences in cost of $\frac{1}{16}$d. or even $\frac{1}{32}$d. a lb. are now vitally important.

Again, it is objected that when mills are working short time and have idle equipment, it takes no intricate costings system to detect the causes of high costs and of wasted time and material. Even in these unfortunate circumstances, however, valuable economies are possible, and it requires a sound costings system to detect where they can be made.

A further objection to the universal adoption of a standard costings system, which is the laudable and eminently practicable object of Mr. Greenhalgh, is that other circumstances prevent the mills from reconciling sales policy with real costs. Spinners are still on the horns of the dilemma, whether it is less unprofitable to close down entirely or to continue to run at a loss. Though there is truth in this contention, it is nevertheless true also that spinners who are ready to take trouble in ascertaining real costs are able to sell less disadvantageously; and there is equal force in Mr. Greenhalgh's contention: "Surely there is some course which will rescue prices from the extreme where spinners simply accept prices which are the best that can be obtained day by day."

Assuming these objections are satisfactorily answered, there is still the practical difficulty of making time for studying and inaugurating a new system by

an already overworked management. Where scientific costings are not already installed, considerable alterations in internal administration are necessary and a costs clerk requires to be specially trained. Given that all concerned are ready to make the extra exertion demanded by the present emergency, this difficulty might be best overcome by each of the mill directors concentrating exclusively on one additional interest to his share of normal routine work. Whilst the buying and selling organisation throws its weight into the controversies involved by the 1¾d. economies, to be made outside the mills, the internal manager may confine attention to scientific costings. Without some such division of the labour, it is physically impossible for management to wage effective war against adverse influences.

There is then to decide which of the textbook systems of scientific costings will best suit the peculiarities of each particular mill or groups of mills. The established costs method obviously satisfies three essential conditions. It is adapted to trade methods. It is understood by those who have to work it. The expense of running the costings is not more than the costings is worth. Scientific costings must also satisfy these conditions. Which, then, is the model that may be most advantageously adopted in, or adapted to, the Lancashire mills.

The present writer bases his opinion on his own practical experience in spinning costings, and can heartily commend the system devised and elaborated by Mr. F. Greenhalgh. His system provides, first, for the ascertainment of real costs on the soundest scientific costings principles, secondly, for an automatic check of the estimates on which the working costs are based, and, thirdly, a standard enabling all mills, no matter how circumstanced, to cost on a comparable basis. The objects respectively are, first, to determine which yarns over the mill range are most remunerative, *i.e.* when compared with the market scale of prices; secondly, to enable costs modifications when and where economies eventuate; and, thirdly, to facilitate the co-operation of the spinners in a common sales policy, if ever that should prove practicable.

Mr. Greenhalgh advocates the adoption of his system in its entirety by all mills, irrespective of their special circumstances. The only reservation we have to make is that, for individual mills in which every department is under constant and close supervision by the directorate, the system is perhaps unnecessarily complicated. It may, however, be readily adapted in a simplified form. In these particular mills a six-monthly check—as against Mr. Greenhalgh's provision for monthly checking—will be adequate, at any rate, in initiating the system. As, however, the costings staff grows familiar with the system, and as satisfactory results warrant the directorate's requiring a greater finesse in the costings, the system may be further developed. That is to say, costings evolved, as experience proves desirable towards greater and greater perfection, will both prevent confusion and be better adapted. For directorates controlling groups of mills and large combines—where "the eye of the master" over long periods must necessarily be absent from the several departments, and where the expense of a fully-staffed costings department presents no serious difficulty—the monthly check is indispensable; and Mr. Greenhalgh's system may be best adopted *in toto*.

Though, at five guineas, these volumes may appear expensive, the matter is well worth the money. They should be available for study and reference in every Lancashire spinning mill, whether the mill already costs scientifically or not. Even if the system is not adopted or only adopted in part, they could be read and re-read with advantage by all responsible for costs estimation. To those who have painfully followed scientific costings, as expounded in some other text-books, and have been under the irritating necessity of interminably turning pages, in aligning text with forms and examples, the boon of a separate folio of illustrative forms will be received with heartfelt appreciation. This is only one of many details, in the presentation of his matter, evidencing the consideration that the author consistently shows for his readers. The industry may indeed congratulate itself on the emergence of so capable a guide. "Trade Organisation in Cotton Spinning" will doubtless be recognised as a classic before many years have passed; and the author's promise to publish further volumes on weaving and finishing costs is to be welcomed.

As, however, scientific costings, no matter how lucidly and logically presented, still remains a subject of some difficulty, it might be worth the industry's while

to set up a Costings School in which costings clerks and future mill directors might have adequate training. Needless to say, the suitable director and teacher would not be hard to find. E.E.C.

Tables of Cotton and Textile Manufacturing Constants. Compiled by W. H. Slater. Published by the Lancashire Statistical Service, 26 Cross Street, Manchester. 5s. post free.

A table of cotton constants which should prove serviceable to cotton mill managers, salesmen, brokers, and users of raw cotton. These constants are provided to enable users to find the cost of clean cotton in a pound of spun yarn in conformity with market-price fluctuations. The table includes both waste losses in cleaning and regain during conditioning. These tables also admit of utilisation in other ways which will suggest themselves to the user. The whole is suitably mounted on card and varnished. T.

Chemical Engineering and Chemical Catalogue. Sixth edition. Edited by Dr. D. M. Newitt. Published by Leonard Hill Ltd., London. (394+lxviii pages. 15s. nett.)

This book of reference contains a catalogue of chemical products; a catalogue of plant and apparatus; an alphabetical index of chemicals and plant; an index to commodities; an index in Spanish; an index to trade names and trade marks; and an index to industrial applications. The tables and data section contains notes on the selection of material for the construction of industrial plant; conversion tables; strengths of material tables; thermometrical tables; compressor; refrigeration shafting, and belting tables; and miscellaneous tables. It is completed by a section devoted to technical books which is divided into subject and author sections. The words of Sir Robert Hadfield, who writes the foreword, may be quoted as adequately describing this production: he says "of the numerous industrial publications which come to my notice, there are none which appear to me to combine so clearly and fully the knowledge and needs of the scientist with those of the manufacturer." The writer can only suggest one matter that, in his view, needs alteration. It is surely logical to consider first the needs of one's firm and to consult books, reference tables, etc., first and then to look up particulars of manufacturers, agents, etc., to supply one's needs. In other words the first section of this book should be last. T.

Shirley Institute Memoirs, Vol. VIII, 1929. Published by the British Cotton Industry Research Association, Didsbury. (210 pp. plus Index.)

This interesting compilation, comprising thirteen papers, represents a fraction of the work carried out by the staff of the British Cotton Industry Research Association during the last year. The papers, which are excellently presented, treat of certain fundamental properties of cotton and cotton cellulose which may have a direct technical bearing. A number of the papers are concerned with adsorption and absorption phenomena, with the various physical properties of cotton and with certain methods for the mathematical analysis of experimental data.

Papers of special interest are those by S. M. Neale on the Swelling of Cotton Cellulose, and by Dr. Clibbens and his staff on the Reactivity of Plain and Mercerised or other Swollen Cottons. The former research, when completed, will doubtless be of high scientific value, while the investigations on the reactivity of unmercerised and mercerised material provide a valuable chemical test for determining the efficiency of commercial mercerising processes.

An ingenious optical method for analysing data for hidden periodicities is described by G. A. R. Foster, while a further paper deals with statistical analyses.

The various papers are of course highly scientific communications and may not, therefore, appeal directly to those connected with the purely technical branches of the textile industry. Excellent summaries are given in each case which provide for the non-scientific an accurate précis of the contents of each paper.

F.L.B.

Reports on the Progress of Applied Chemistry 1929. Published by the Society of Chemical Industry, London. (707 pp. plus Index.)

The annual reports of the Society of Chemical Industry on the Progress of Applied Chemistry deal with the latest developments in various branches of chemical technology during the last year. They include two sections of interest to textile

technologists, namely, the section dealing with Fibres, Textiles, Cellulose, and Paper, by Dr. J. C. Withers, of the British Cotton Industry Research Association, and a section on Bleaching, Dyeing, Printing, and Finishing, by Messrs. L. G. Lawrie and N. Chappell, of the British Dyestuffs Corporation. The former section contains 135 references of published papers and patents, while in the latter section 125 references are given. Both sections are extremely well written, while careful selections of the more important published observations occurring under certain specific heads have been made in each case. The compilation of these reports involves an enormous amount of work, and the authors of these sections are to be congratulated on the discrimination they have exercised in the preparation of their reports and the accuracy of their préces. F.L.B.

Enzyklopädie der textilchemischen Technologie. By Dr. P. Heermann (with 23 collaborators). 1930: Verlag Julius Springer, Berlin. (Pp. 970, 372 illustrations; £3 18s. od.)

This extremely valuable handbook deals with those textile processes and investigations in which chemistry is applied. It is arranged on a novel plan, under main subjects ordered alphabetically. Thus, it begins with Aniline Black, proceeds to "Appretur" (finishing), Bleaching, Bookbinder's Cloth, Chemicals used in Finishing, and so on to Turkey Red Dyeing, Water, and finally "Zeugdruck" (calico printing). Each main subject is contributed by a special writer, and these include most of the well-known German authorities. There is a separate contents sheet under the main headings, Fibres, Chemicals, Dyes, Water, Tests, Bleaching, Dyeing, Printing, and Finishing, which indicates at a glance the subjects dealt with in the main portion of the book. In addition, Dr. Heermann has himself prepared a thorough index, and this is supplemented by an index of all the dyes mentioned in the text. It is quite easy, therefore, to find one's way about in the book.

Each chapter is preceded by a list of references to specialised information on the subject about to be discussed, and there are frequent citations of books and periodicals in the text. The reviewer has very carefully examined these for references to British work and is astonished to find how very little of the research published since 1920 has been assimilated by the eminent collaborators in this book. There does not appear to be any reference, for example, to work published in this *Journal* on the regain of cotton, the swelling of cotton by alkalis, the effect of the reaction of the chemic in bleaching, or the control of bleaching by measuring the viscosity of cellulose in cuprammonium solution. Nor is there any account of the mercerisation of fabrics containing rayon.

The reader should, therefore, regard the book as an encyclopædia of *German* work, and as such it is extraordinarily complete and useful. J.C.W.

THE JOURNAL OF THE TEXTILE INSTITUTE

Vol. XXI AUGUST 1930 No. 8

PROCEEDINGS

London Section

Meeting at Clothworkers' Hall, Mincing Lane, on 7th April 1930;
Mr. E. Wigglesworth presiding.

TEXTILE RESEARCH AND ITS EFFECT ON MANUFACTURED GOODS

The Chairman said he had much pleasure in introducing Mr. W. Kershaw, of the Research Department of the Bleachers' Association, Manchester. A previous lecture by Dr. Gibson, Director of the Linen Industry Research Association, proved to be most interesting, and showed the distributive trades that the textile industry of this country was by no means asleep. He was sure that many who attended that lecture were astonished at the tremendous amount of work done in research in the linen industry. The Section Committee thought it would be most interesting to have an account of research work in the cotton industry, which Mr. Kershaw was there to give them. All his life Mr. Kershaw had been associated with the scientific and technical side of the industry, and he, the chairman, was sure that those present would listen with great pleasure to his paper.

After outlining the principal historical facts in relation to discoveries in chemistry and physics, and tracing the effects of their application in the textile industry, the lecturer said that although a large expenditure of money and time was being directed in this country to scientific research in relation to the cotton industry, yet we held no monopoly in this connection. The quality of our research, however, was of a very high order and not excelled by any other country. The character of the reserach work varied, that of the British Cotton Industry Research Association being comprehensive and over a wide field, and that of other bodies—research departments of large associations, individual firms, technical colleges and universities—varying in accordance with special requirements and being intensive in some branches and unimportant in others.

Understanding that he was addressing many whose interests were bound up with salesmanship and distribution, he would like to say that however much scientific work was introduced into the production of fabrics, it would be of no avail if the goods were not eventually handed over the counter. The gap between fundamental research and distribution might appear to be extremely wide, but the connection was important.

Rayon, in a comparative sense, had only of recent years been used in the cotton industry, and the quantity taken up by cotton manufacturers and subsequently finished was now on so large a scale that research in the cotton industry

must embrace rayon, commencing at the finished products of the rayon manufacturer which was a raw material to the cotton manufacturer. Research had played a very important part in the investigation on the production of chemically purified cellulose and the amount of time and money expended thereon since 1914, in ratio to the value of the product, had not been exceeded in any other industry. The result had been the foundation and expansion of new industries.

After dealing with the fundamental properties of raw cotton and identification, the lecturer turned to the spinning of cotton and also the spinning of staple fibre produced by the viscose process. The production of staple fibre was now becoming a distinct manufacture operated with the same care and control which experience showed to be so necessary in the case of the continuous rayon filament. One writer had stated that the actual advances made in the quality of staple fibre seemed to imply that Lancashire might usefully think more of their industry as a textile industry than as merely a cotton industry.

A modern spinning mill of to-day was more efficient than one of so recent a year as 1921, although it might be true that even the most highly efficient mill could not be run to-day at an adequate profit, as important external factors had to be considered.

Sizing and weaving were next dealt with, and the lecturer said that research in the matter of sizing was now of great importance, whilst sizing and desizing should be investigated together.

Turning to finishing processes, he said that whilst bleaching, dyeing, and printing could be brought down to exact science, this was not the case in regard to finishing. The very terms employed in the industry—fullness, handle, etc. —indicated the difficulty. It was notorious that the industry was carried on successfully without the protection of patents.

The attempts to make cotton permanently similar to the more valuable fibres had their success in mercerisation. The production of permanent, silky lustre by mercerising was an *epoch-making* novelty and instigated further attempts to change cotton fundamentally by chemical means. Although in the first instance the more valuable natural fibres—silk, wool, and linen—were the ideals striven for, further development led to perfectly new and hitherto unknown products.

On the basis of the mercerisation process, a considerable branch of industry had been built up embracing new finishing process for which some years ago the suitable expression "permanent finishing" was coined. An all important requirement, in addition to the finishing effect, was that of resistance to laundering. It was now possible to mercerise fabrics containing cotton, regenerated cellulose rayon, and acetate rayon, so that the rayons suffered little or no deterioration. All these processes, usually termed chemical or permanent finishes, provided great scope to the designer and producer of cloths.

The practical achievements in chemical finishing provide a good example of how scientific research affects the textile industry.

Concluding, Mr. Kershaw referred to the production under specification of fabrics for special purposes, including industrial uses, and said he hoped that the ground he had covered would help the distributors towards a fuller realisation of the value of research in relation to the goods which they handled.

DISCUSSION

The Chairman said he was sure they all realised the tremendous amount of work going on all the time behind the finished products they distributed, although only a fragment of it was apparent on the surface.

The lecturer, asked what was meant by a "staple" fibre, said it was the common name for artificial silk spun continuously and then cut into fibres of 1½ to 2 inches in length.

Mr. E. B. Fry said he took it that the fibre was cut or broken up to make short fibres to use on the ordinary type of machinery. Of course, in the case of silk, it was the waste fibre which was simply broken up to use in the same way: was that done for convenience? He also asked what was the average length of the cut fibre.

The lecturer said it was so cut because machines were not yet devised to spin artificial silk intermittently, though attempts were being made to do so. The average fibre length was 1½ inches.

Replying to Mr. Mason, the lecturer said staple fibre came from the Germans and was used very largely in 1913–14.

Mr. Mason further commented that, in the textile trade, terms were getting mixed up. He thought there ought to be more clarity about the terms used at the spinning end of the trade. He thought the Institute might make a protest against this confusion of terms. It was not very satisfactory. He would also like to emphasise the weakness of spun rayon when wet; that was a very serious objection. It was true that most types of rayon now on the market regained strength when dry and were quite satisfactory if not abused in their wet state, but it was very difficult to inform users in that respect. As to bleaching, he asked if it were wise to sacrifice the strength of the fabric or the strength of the yarn to obtain a pure white.

The lecturer said it was not necessary to sacrifice strength—a good white could be secured with preservation of strength.

A questioner asked what margin of variation was customary in regard to strength and stretching tests. Reference had been made to Shirlan, which the questioner understood was a substitute for zinc chloride in sizing. Under certain conditions a cotton fabric used in conjunction with leather would become stained. Would Shirlan not stain in the same way?

The lecturer said that was a matter for co-operation between the leather industry and the cotton industry. He thought information could be had on that point almost immediately from Dr. Pickard, the Director of the Shirley Institute. He could not answer the question regarding tolerances. The question of standards wanted going into very thoroughly in this country. It was a matter that the Textile Institute had under view.

Mr. P. J. Neate (Clothworkers' Company), proposing a hearty vote of thanks to Mr. Kershaw, said he did it with the greater pleasure because the lecture had been given in the Clothworkers' Hall. The Clothworkers' Company were much indebted to Mr. Kershaw and to other lecturers for improving and helping forward the industry from which they took their name. The Clothworkers' Company, however, had not only taken the name, he was glad to say, but for centuries had taken a very great interest in the cloth industry. Although some of the most brilliant work in research had been done by Englishmen, unfortunately it did not materialise so rapidly as it might have done. The only other thing he would suggest—and that here he felt he was almost treading on forbidden ground—was that the present Ministers of the Government should have listened to that lecture and been convinced in spite of themselves that the way to increase employment in this country was to subsidise research rather than to adopt some of the ineffective measures that had been tried.

Mr. Mason, seconding the vote, which was unanimously and heartily accorded, said he was sure he was voicing the feelings of all when he said they had enjoyed the lecture and hoped Mr. Kershaw would come along another time and give them some more of it.

The lecturer suitably acknowledged the vote.

LONDON SECTION—ANNUAL MEETING

The Eighth Annual Meeting of members of the London Section was held at *104 Newgate Street, on Tuesday, 15th April, at 6.30 p.m.* Mr. Frank Henley occupied the chair. The minutes of the previous annual meeting (30/4/29) having been read and approved, the chairman read the Report of Section Committee, which was accepted. This report made reference to the severe loss the London Section had sustained in the death of Sir Frank Warner. He had been instrumental in bringing about the formation of the London Section, and steps had been taken to bring to the notice of Council the desirability of instituting some form of memorial to perpetuate his association with the Textile Institute. The report dealt also with membership of the Section; the lecture programme; visits to works; and the Autumn Conference of the Institute which was held in London, the programme for which event proved most interesting and attracted a large number of members. It had been made noteworthy, too, by the invitation to a reception extended by the Clothworkers' Company to the members attending the Conference.

The Honorary Secretary, Mr. A. R. Down, read the result of the ballot for membership of the London Section Committee, which resulted in the following names being recommended to Council—Messrs. A. B. Ball, C. N. Colton, A. R. Down, E. B. Fry, A. E. Garrett, A. Gowie, F. Henley, H. B. Heylin, J. Howard, C. W. James, A. Mason, R. S. Meredith, L. J. Mills, P. J. Neate, J. R. Peers, G. A. Rushton, A. B. Shearer, W. C. Whittaker, E. Wigglesworth, and S. A. Williams.

By unanimous vote Mr. F. Henley was re-elected chairman and thanked the members for their kind remarks and for their continued confidence in him. The following were nominated vice-chairmen—Messrs. E. B. Fry, A. E. Garrett, P. J. Neate, and E. Wigglesworth. Mr. A. R. Down was re-elected Honorary Secretary, and Mr. G. A. Rushton, Honorary Assistant Secretary. Hearty votes of thanks were accorded to the Worshipful Company of Clothworkers and to the Drapers' Chamber of Trade of the United Kingdom for the assistance rendered to the London Section during the past session. A vote of thanks to the chairman concluded the meeting.

SCOTTISH SECTION—ANNUAL MEETING

A meeting of the Scottish Section was held in Dunfermline on Thursday, 12th June, and although it was open to members and friends, it is to be regretted that more did not take advantage of the interesting programme arranged. After inspecting the Textile School, the party visited the Linen Damask Works of Messrs. Hay & Robertson, where they were welcomed by Mr. Angus Robertson on behalf of the firm. Mr. Robertson said that he much appreciated the good work of the Textile Institute in arranging visits to places of interest in connection with the textile trade, and suggested that by so doing the members were co-operating with one another to mutual advantage. Thereafter, the party was conducted through the weaving factory and embroidery department, and afterwards lunched with Dunfermline Civic Club, where an excellent address was given by Sir Samuel Chapman, M.P.

In the afternoon, visits were paid to the Carnegie Baths and Clinic, the Craft School, and Carnegie's Birthplace and Memorial. On the invitation of the Carnegie Dunfermline Trust, tea was served in the Glen, where the party was received by Ex-Provost Norval (Chairman), and other members of the Trust. Mr. J. MacPherson Brown suitably acknowledged the hospitality of the Trustees, and also conveyed the thanks of the members to Messrs. Hay & Robertson for the opportunity of visiting the works earlier in the day. After tea, the party visited Dunfermline Abbey, and later spent some time in the Glen, where music was provided by the band of the Cameron Highlanders.

YORKSHIRE SECTION—ANNUAL MEETING

The Annual Meeting of the Yorkshire Section was held at the Midland Hotel, Bradford, on Thursday, 14th May 1930. Mr. Arthur Saville (Vice-Chairman) presided, in the absence of the Chairman, Mr. R. G. Bailey. Mr. Saville was supported by the Hon. Secretary, Mr. C. S. Ickringill, and the Acting General Secretary was also present. Apologies for absence were read from the President, from Mrs. Binns for Mr. H. Binns, A. R. Baines, J. Dumville, T. H. Robinson, H. Jaques, and A. F. Barker.

The Chairman said he felt sure that all those present would join him in regretting Mr. Bailey's inability to attend, and his expression of hope that Mr. Bailey would have a safe and profitable journey abroad.

He called on the Hon. Secretary to read the minutes of the previous meeting (25/3/29), which after due authorisation by the members present, he signed.

The Chairman spoke of the year's work in the Institute as a whole, and by the Yorkshire Section in particular. During the year, he pointed out, the Institute had made considerable progress. The library had been placed upon a firm basis and a catalogue was now available. It was far from being complete, but had already proved its usefulness. The Autumn Conference in London had been a marked success both socially and educationally. An increase in Institute members had been recorded and interest in the work of the Institute had shown marked increase. Of the work of the Yorkshire Section in particular, Mr. Saville said the two luncheon meetings—one addressed by Sir Josiah Stamp, at Bradford, and the other by M. Dubrulle, at Huddersfield, had been notably successful. Bradford as a municipality had given a lead in welcoming the Institute which he was glad to see had been followed by the Mayor of Bolton, who, at the Annual Meeting of the Institute, had accorded its members a civic welcome. Five joint meetings with Textile Societies had been held, and the Section Committee had met on five occasions also, while the Executive had met a further seven times.

The Hon. Secretary, Mr. C. S. Ickringill, had been appointed Secretary of the Special Committee to consider the question of relationships between Headquarters and Sections. Many other Yorkshire Section members had taken prominent place in the work of the Institute. A Yorkshire Section student had been successful in one of the Institute Competitions, and in regard to the Fellowships and Associateships of the Institute, Yorkshire Section had achieved notable success. The total elections to the Fellowship or Associateship represented 21% of the Institute membership, but of the Yorkshire Section 31% had been so elected.

He moved a very hearty vote of thanks to the Chairman and other Section officers for their services. This was accorded unanimously.

The Hon. Secretary read the result of the ballot for the election of the Section Committee as follows—*Elected:* Messrs. R. J. H. Beanland, H. Binns, G. Garnett, E. T. Holdsworth, C. S. Ickringill, H. Jaques, E. Midgley, A. Ollerenshaw, J. Robinson, W. S. Stansfield.

The scrutineers, Messrs. E. Handy and T. H. Robinson, were thanked for their services.

The meeting was thrown open to discussion with a view to securing suggestions for improving the value of the Institute and of the Yorkshire Section. Attention was drawn to the fact that in 1931 the Institute attained its majority, and members were also asked to encourage younger members to proceed, if at all possible, to the Associateship and Fellowship of the Institute.

The discussion was general, Messrs. Stansfield, Beanland, Richardson, Ollerenshaw, Midgley, Handy, Ickringill, and Wilson taking part.

The meeting closed with a vote of thanks to the Chairman and Section officers.

NOTES AND NOTICES

Council Meeting Decisions

At the July meeting of the Council of the Institute, the most important item for consideration was that of the new Scholarship Scheme. The scheme and conditions as to candidature were presented in printers' proof form, and substantial agreement with the provisions, which had received exhaustive consideration by the Sub-Committee concerned, was readily conceded by members present. Some discussion took place, and possible modifications in the scheme were suggested. However, on the score of the consideration that no really useful amendment of the scheme was likely to accrue except by way of actual experience of operation of the conditions as drafted, the scheme was unanimously adopted, and the Sub-Committee were warmly thanked for their excellent endeavours in framing the draft. The final date for receipt of applications for the Scholarship offered was fixed—15th September. And, in order that the next Council meeting may be able to deal with any recommendations as to award of the Scholarship, it was decided that the next meeting—there being no meeting in August—shall take place on Wednesday, 24th September.

Institute Scholarship Scheme

As announced on a supplementary sheet issued with last month's *Journal*, the Scholarship Scheme of the Institute, which is the outcome of a special donation to the Foundation Fund of the Institute from the Cotton Reconstruction Board and the Cotton Trade War Memorial Fund, has now been launched, and has so far met with a satisfactory measure of general approbation. It was at one time hoped that the annual revenue would be adequate for the provision of two scholarships—one referring to cotton spinning and the other to cotton weaving. For the present, however, only one award will be made and the award will go to the best candidate from either section. The outstanding feature of the scheme is that competitors will be drawn from the evening-class type of textile student, and the successful applicant will be afforded not only opportunity for extended and advanced technical training, but will be provided with a reasonable maintenance allowance, according to circumstances, during the period of further training. It is stipulated that candidates must already have obtained the Full Technological Certificate of the City and Guilds of London Institute, an attainment considered not only desirable but essential for the individual who is likely to benefit substantially from the operation of the scholarship. Candidature is confined to young craftsmen actually engaged in cotton spinning or weaving, and the certificate aforementioned must refer to the section engaged in. Already a considerable number of applications, the last date for receipt of which is 15th September 1930, have been received.

Institute's Annual Competitions

The details of the annual competitions of the Institute—the competitions concerning the design and structure of textile fabrics, and the production of novelty yarns—were considerably amended in 1929. The Competitions Committee, therefore, have not recommended any real change in the terms of the next prospectus, and the Council has agreed to the issue of the programme for the coming year, as previously. The Competitions Committee, however, referred to Council a communication from Leicester inquiring whether provision could not be made whereby students concerned with the knitted structure of fabrics could participate in the Institute's competitions. The opinion was expressed at last Council meeting that the inclusion of the knitted fabric was highly desirable, and it was recognised that it might be necessary to add a special competition. Now that a Midlands Section of the Institute has been created and a Committee appointed, it was promptly agreed to refer the whole matter to the consideration of the Committee for report and recommendations to Council.

Continental Visit Proposal Abandoned

In a recent issue of this *Journal*, a proposal to organise a visit of inspection of textile works in the Lyons district of France was announced and members of the Institute were invited to notify their preparedness to take part. Owing to the very small response to the announcement, however, the Council decided, at its July meeting, that the prospects of a satisfactory attendance did not justify proceeding further in the matter, The proposal is, therefore, abandoned.

REVIEW

Final Report on the Third Census of Production of the United Kingdom, 1924. The Textile Trades. H.M. Stationery Office. (4s. 6d.)

This statistical record of production, wages, employment, power and machinery equipment in the textile trades is divided into the following sections—cotton; woollen and worsted; silk and artificial silk; jute, hemp, and linen; hosiery; textile finishing; lace; rope, twine, and net; elastic webbing; coconut fibre, ramie fibre, horsehair, and feather; flock and rag; and packing. The figures given apply to the census years 1924, 1912, and 1907; and, wherever possible (the census requirements in the stated years not being the same in every respect), comparisons are drawn. Owing to rapidly changing conditions between the year 1924 and the issue of this report, however, these comparisons and the statistical data generally are of relatively small practical value in the present emergency.

Among many points of interest, perhaps the most interesting are the estimates provided of the nett output for each trade, i.e. the value of the gross output less the cost of materials utilised in production, which constitutes the fund from which wages, salaries, rent, and royalties, rates and taxes, advertisement, sales expenses and all other similar charges have to be provided, as well as profits. As an indication of what valuable information might be derived from the census figures, these estimates are of significant value. If they were sufficiently up to date and also completely reliable, they would provide an invaluable basis for interpreting present conditions and for indicating the corresponding lines of progress. The 1924 estimates are neither. The proportion of material cost to gross output value, year by year, is normally variable. Circumstances since the war have been abnormal, and the extraordinary position relative to stocks of materials in the mills during the early post-boom years was still in evidence in the year 1924. Then the lag between contracting for materials and estimating the value of the product also militates against accurate nett-output deductions. Owing to these discrepancies, the estimates here provided are especially susceptible to misapprehension, by those not fully conversant with each trade, just as they fail to satisfy the requirements of those observers who might make best use of them. The discrepancies could be overcome by instituting a continuous census, which, as a matter of yearly routine, might prove less burdensome than an occasional demand on those supplying the initial data, and by the issue of a bare compilation of the statistics annually.

In many other respects, and notably for the purpose of contrasting the relative positions and the relative rates of progress, down to the year 1924, of the several textile trades, this report is an invaluable mine of information. F.E.C.

GENERAL ITEMS AND REPORTS

Research Scholarships

Applications are invited for the following Research Scholarships tenable at the Technical College, Huddersfield, during the coming Session—

JOSEPH BLAMIRES RESEARCH SCHOLARSHIP FOR RESEARCH IN COLOUR CHEMISTRY

Value £100 a year with remission of fees.

BRITISH DYES RESEARCH SCHOLARSHIP FOR RESEARCH IN COLOUR CHEMISTRY

Value £75 a year with remission of fees.

The object of these scholarships is to afford facilities for research in connection with Coal Tar Colour Chemistry. The research is to be carried out in the

Department of Coal Tar Colour Chemistry at the Technical College, Huddersfield, under the direction of the Head of the Department. In the award of these scholarships preference will be given (other things being equal) to students born or resident in the County Borough of Huddersfield. The scholarships will be awarded in the first instance for one year, but may be renewed for a second year, or in exceptional cases for a third year.

Further particulars and forms of application may be obtained on application to the Principal, the Technical College, Huddersfield.

Panel of Expert Translators

The attention of the Council of the Association of Special Libraries and Information Bureaux was drawn to the difficulty often experienced in finding translators for pieces of work which require both the necessary linguistic qualifications and a knowledge of the special subject concerned. Accordingly they appointed a Committee to consider this problem and to report upon it. The Committee proposed a scheme whereby the Association should act as intermediary between translators and users by establishing a Panel of translators possessing the double qualifications of proficiency in one or more languages and expert knowledge of one or more subjects.

A translator who wishes to be registered on the Panel is required to answer a questionnaire (which can be obtained by application to the Secretary of the Association),* which is framed so as to provide the Association, in addition to necessary particulars, with full information regarding the applicant's qualifications, linguistic and technical. As a rule only individuals are eligible for registration, but commercial translating bureaux may apply for registration in respect of full-time employees, or by satisfying the Board of their ability to undertake high-class specialised work. An applicant may apply to be registered for any foreign language and for any number of foreign languages, but a high standard will be required by the Board. An applicant may apply to be registered for any subject and for any number of subjects, provided that these are sufficiently specialised. Applicants are required to pay a fee of one guinea when they send in their applications. In the case of accepted applications, it includes the first year's registration fee. Thereafter each year when (in order to keep the Panel up to date) registered translators are asked to confirm the particulars regarding their address, etc., they will be required to pay a registration fee of five shillings. The Association does not guarantee work to registered translators, but intends to advertise the Panel so far as funds received from applicants permit, but accepts no obligation as to the success of the scheme. The fees suggested for registration have purposely been made as moderate as possible; experience will show whether they may need increasing to afford adequate publicity.

Palestine Government Gives Trees and Eggs to Encourage Silkworm Silk

Following a report by the Silk Advisory Committee to the Colonial Office, that local conditions are suitable for the production of silk, the Palestine Government has decided to promote this industry. Government nurseries are distributing, without charge, young mulberry trees to those willing to undertake the planting and tending them for the purpose of sericulture. Silkworm eggs of approved type are now to be distributed as far as the resources of the Department of Agriculture permit. An illustrated leaflet dealing with the mulberry tree, and printed in English, Hebrew, and Arabic, is being circulated. A second leaflet on silkworm breeding is in course of preparation. Lectures and practical demonstrations are being organised, and sericulture has been introduced in certain Government schools.

N.N.S.

* 26 Bedford Square, London, W.C.1

THE JOURNAL OF THE
TEXTILE INSTITUTE

Vol. XXI SEPTEMBER 1930 No. 9

PROCEEDINGS

NOTES AND NOTICES

Institute Sections and Programmes

The Committee of our Lancashire Section has issued a programme of meetings arranged up to and including December next. Four of the meetings at which papers will be read are to take place at Headquarters—two of them at luncheon hour and two in the evening. The evening fixtures are arranged to meet the expressed desires of members who have written suggesting variation in the time selected in order to meet varying circumstances of convenience for attendance. Meetings other than at Headquarters are to take place at Todmorden, Burnley, and Stockport. The first on the programme is a lunch-hour meeting fixed to take place at the Institute, on Friday, 26th September, when Mr. John Crompton will doubtless have something quite interesting to say in regard to his recent world tour. The second meeting is fixed for Todmorden on the evening of 1st October, when Mr. W. T. Shackleton will contribute a paper on "The Case for Rationalisation." Particulars of other meetings are available on the programme and they will be announced in the Journal and by circulars to members in the Lancashire area. Stockport is to be visited for the first time—on the evening of 26th November, when Mr. Walter Bailey will give a lantern illustrated lecture on "Developments in Winding and Doubling." This meeting will be held at Stockport College, and the Principal, Mr. G. Wood, M.Sc., is kindly co-operating as to the event which is of particular local interest.

London Section Arrangements

Mr. A. R. Down, the Hon. Secretary of the London Section, has forwarded committee minutes which show that arrangements are proceeding satisfactorily for the promotion of four special lecture meetings and four meetings for informal discussions. Two lecture meetings are announced—27th October, at Clothworkers' Hall, paper on Fibres (exact title to be announced later), by Mr. E. Wigglesworth, F.T.I.; and 17th November, paper on "Distributive Problems," by Mr. J. Guilfoyle Williams, at the Barrett Street Trade School.

Midlands Section Meetings

The Provisional Committee of the newly-created Midlands Section of the Institute has got quickly to work in the matter of arrangement of meetings, and the Hon. Secretary (Mr. J. Chamberlain) has notified Headquarters of completion of information for announcements for the coming session. The Committee decided at the outset on a not too crowded programme for their initial endeavour, and accordingly, there are to be meetings at Nottingham, Leicester, and Loughborough, with two visits to industrial establishments interspersed between the

dates decided upon. On Wednesday, 22nd October, at 8 p.m., at the University College, Shakespeare Street, Nottingham, Mr. Arnold N. Shimmin, M.A. (Leeds) will lecture on "Some Reactions of Foreign Competition on British Trade." On Wednesday, 10th December, Mr. W. Kershaw, F.T.I. (Manchester) will give a paper at Leicester on "Research in the Textile Industry"; and on 10th February (1931), Mr. S. Kershaw, F.T.I. (Bradford) will contribute a paper on "Yarns for the Hosiery Trade," at Loughborough. On the afternoon of 13th November a visit will be paid to the works of Messrs. J. B. Lewis & Sons Ltd., Nottingham, and on the afternoon of 22nd January 1931, the works of Messrs. Wolsey Ltd., Abbey Meadow Mills, Leicester, will be visited. Members in the Section area will receive separate notices of each event.

Papers for Institute Section Meetings

The Propaganda Committee of the Institute was recently requested to give consideration to the question of papers or lectures available for Section Meetings, and, if possible, suggest means for assisting Section Committees in this connection. The Committee quickly arrived at the conclusion that individual selection of subjects to be dealt with in the form of papers or lectures might be highly advantageous. It was therefore decided to circularise a number of members—particularly members of Councils and Committees—asking for recommendations. The following statement appeared in the circular—"The Propaganda Committee has decided to direct its attention to the possibility of offering to the Sections one important Paper or Lecture, or it may be a short series of lectures, on a special subject of more or less general interest. In the selection of such a Paper, the possibility of remuneration to the contributor would not be excluded, and the Paper, or short series (two or three instalments) might be presented before several of the Sections in the same session. The Committee would be glad if you would kindly consider the proposal, and if you are able to recommend a subject, either with or without suggestion as to author—preferably with—they would be grateful. The proposal is not put forward to retard the efforts of Section Committees with regard to programme of papers suitable for their own particular areas, but to supplement and facilitate their endeavours and stimulate sectional interest." If any Institute member who has not been directly circularised could offer any suggestion on the lines indicated by the foregoing quotation, the Committee would heartily welcome any such communication on the subject made to the General Secretary.

Institute Scholarship Applications

Over 40 applications were received for the Scholarship, open to young craftsmen engaged in the cotton spinning or weaving industry of this country, announced in our July issue. Immediately after the last date for receipt of applications (15th September), the Committee charged with the duty of selection met and considered the records presented by the respective candidates. The scholarship is for a period of three years and provides for day training at a technical college followed by one year of industrial experience abroad under such arrrangements as may be effected. The scholarship is planned in accordance with the terms of a grant to the Institute from the Cotton Reconstruction Board and the Trustees of the Cotton Trade War Memorial Fund. The principal aim of the scheme is to afford whole-time technical training to a selected worker calculated, by attainments at evening classes and other records, to give promise of a satisfactory yield. In addition to payment of fees, a maintenance allowance will be made according to the circumstances of the candidate selected, and for the first two years the maximum total annual value is placed at £175, and, for the third year, £300. The maintenance allowance is provided for, as it is recognised that a selected candidate may require income for maintenance as an alternative to wages earned in ordinary employment.

Library Catalogue

The Library Committee of the Institute again draws attention to the Library Catalogue, which is available at the price of 6d. post free. Copies may be obtained from the Institute headquarters or from the Honorary Secretaries of Sections. The Committee is convinced that familiarity with the contents of the Library, which possession of a catalogue makes possible, is of the utmost benefit to members. The rules governing the lending of books and periodicals are simple and extended use of the Library would be welcome.

Employment Register

In connection with the Employment Register kept at the Institute with a view to the introduction of suitable candidates for employment vacancies, the following announcements relate to members who have filed particulars of their qualifications and experience, and who seek employment. Employers may obtain further particulars by application to the General Secretary, quoting reference number—

No. 40—Seeks post as Worsted Spinning Manager or Technical Assistant. Age 26; over nine years' experience; winner of several scholarships for technical training; experience in teaching and lecturing.

No. 41—Desires post as Textile Machinery Salesman. M.Sc.Tech., F.T.I.; engineering shop and cotton mill experience; also lecturing, teaching, and research experience; knowledge of Spanish.

No. 42—Worsted Spinning Overlooker. Age 24 years; seeks post as Spinning Mill Manager; Full Technological Certificate of City and Guilds, and several evening course certificates.

Textile Institute Diplomas

Elections to Fellowship and Associateship have been completed as follows since the appearance of the previous list (July issue of this *Journal*)—

FELLOWSHIP

FERNANDEZ, Vincent Anthony (Bombay, India).
OLDHAM, George Thompson (Huddersfield).

ASSOCIATESHIP

CHANDLER, William (Oldham).
COATES, Sidney (Elland, Yorks.).
GREGSON, Norman (Bolton).
GRIERSON, James (Bolton).
HAYES, Joseph (Manchester).
HOLT, John (Bolton).
KAY, Herbert (Bolton).
MITCHELL, Joseph (Preston).
PARKES, George Townend (Middleton).
SAXTON, William (Hyde).
TARBUCK, Sidney (Atherton).

REVIEWS

Technologie Der Textilfasern. Band V, Teil 1. Der Flachs (flax). 1. Abteilung. Botanik, Kultur, Aufbereitung Bleicherei und Wirtschaft des Flaches. (Botany, Cultivation, Preparation, Bleaching, and Economics of Flax.) Edited by Dr. R. Herzog. Published by Julius Springer, Berlin, 1930. (427 pp. Price, bound, 54 R.M.)

The book is divided into five parts written by different authors, and is a very valuable contribution to the literature of the subject. It deals with the scientific properties, cultivation, preparation, and economic history of flax, and is a very extensive review of almost every available source of information. There are numerous illustrations, many of which are of historic interest, and every effort has been made to include the most recent work.

The first part (47 pp.), by Dr. C. Steinbrinck, on the structure and chemical and physical properties of the single fibre, will be especially welcomed by scientists, the subject being well illustrated and demonstrated by simple experiments. The work of Nageli, Reimers, and others on the various arrangements of the spiral structure in the wall of different textile fibres is carefully described, and a clear explanation is given of the appearance of flax and ramie in polarised light. The micellar structure of the fibre allows the expansion and contraction caused by the presence of varying amounts of moisture in the cell to take place freely.

As a result of the combined authorship, the work as a whole is rather unbalanced, and the section on the botany and cultivation of flax (149 pp.), by Dr. Ernst Schilling, might be considerably condensed, whilst the part on the bleaching and mercerisation would be of still greater value if it were enlarged. In the first of these two sections so much of the detail given, and often frequently repeated, is only common knowledge, as for example, the effect of thin sowing in producing thick stems, or the methods adopted for the propagation and testing of selected varieties. Amongst other minor criticisms one would suggest that the form of presentation of numerical results is unworthy of the scientific standing of the editor. For example, simple tables such as that of area of stem and number of fibres (p. 123) might be replaced by the correlation coefficient, with its probable error, based upon hundreds of cases, which was published several years ago. Indeed the whole of the section suffers from insufficient evidence; only rarely is the number of cases stated, and when in one of those few instances the number proves to be only ten (p. 149) the reader is inclined to question the value of other figures given. Further, the author has not always chosen the most reliable evidence; for example, the method of estimating the percentage of fibre in a single stem by actual measurement of a perfect section is preferable to the very inaccurate method of chemically or biologically retting the single stem. Scientists engaged on flax problems will appreciate, however, the criticisms and experimental results of the author himself which are not the less valuable for being debatable at times. Those who have devoted much time to the examination of the internal structure of the flax stem will be interested in the example given (p. 112) of a variety selected on the basis of its external appearance proving worthless when it had been carried on far enough to produce sufficient fibre for a scutching test.

The third part of the book (64 pp.), by Dr. Willy Muller, dealing with the preparation of the fibre, gives a very comprehensive survey of all the different methods of retting, accompanied by many good illustrations. Readers will appreciate this useful summary, and although it is necessarily condensed, many practical details are given. The section has been brought up to date by the inclusion of the many mechanical methods of fibre separation now being tried, as for example, the Watson and Waddell process, although in this case the actual details are still secret.

So much useful and interesting information is given in the chapter on the bleaching and mercerisation of flax (28 pp.) that one regrets, as stated above, that the author, Dr. W. Kind, has exercised so much restraint in his treatment of the subject, and one hopes that this will be remedied in later editions.

The concluding chapter (110 pp.), by Dr. Paul Koenig, on the economic history of flax production in different parts of the world, represents a vast amount of laborious research into the statistics of the numerous countries, and one

sympathises with the author in the difficulty of obtaining accurate and reliable figures. In such a mass of data there must necessarily be some incorrect statements as, for example, the area of flax in England in 1922 being over 22,000 acres (p. 372), when actually it was less than half that amount, and the fact that the weight of a stone of flax varies in different parts of Ireland (p. 375), whilst the uniform correct weight of 14 lb. is not given at all. However, the chapter contains many interesting facts not hitherto collected and one gratefully acknowledges one's debt to the author for his contribution. It is a fitting conclusion to a book which has supplied so successfully the need for a complete review of all the published work on flax and the various authors are to be congratulated on having omitted nothing of any importance.

Very few typographical errors were noticed but in order that future editions may be even more perfect, mention may be made of the following—p. 130, P_2O_2 instead of P_2O_5; p. 204, I.W.S. instead of J.W.S.; p. 372, Tifeshire instead of Fifeshire. A.G.D.

Die Jute. Part I. Plant and Fibre Production: Trade and Working: Spinning Mill. By E. Nonnenmacher. Published by J. Springer, Berlin, 1930. (86 R.M. Bound.)

This book is Part 3, Volume V, of the series on Textile Fibre Technology edited by Dr. R. O. Herzog. It contains 571 pages, 95 tables, and 542 illustrations, line drawings, and photographs. The subject is dealt with in three sections, General, Raw Jute, and The Spinning Mill. Section I gives in 30 pages some general remarks on the manufacturing processes and the properties of jute yarn, including calculations of yarn numbers and twist in different systems of units; also descriptions of various methods of testing yarns. Section II on Raw Jute contains 70 pages, giving a botanical description of the plant and describing the operations in plant cultivation and fibre production. Systems of grading and marking are given and the historical development of the jute industry in various countries discussed. The discussion on structure, chemical and physical properties, bleaching and dyeing of jute fibre is illustrated by excellent microphotographs of plant and fibre bundle cross sections and single fibre longitudinal sections. Section III on The Spinning Mill, contains 453 pages, and deals with the subject under three heads, Batching, Preparing, and Spinning, each of which is again sub-divided into subjects such as opening, batching, carding, and so on. Each sub-section is prefaced with a few general remarks on the sequence and purpose of the operations to be described. Each machine is then described in detail, illustrated by photographs and line drawings of the whole section of the machine and larger line drawings of the most important parts. A feature of the book is the method of dealing with the machine calculations by single algebraical formulæ, and the presentation in a condensed form of an immense amount of information relating to constructional details of different makes of machines by the use of tables.

In sub-section 1, Batching is discussed in 42 pages, covering bale openers, batching mixtures, hand and machine batching, the treatment of the root ends and cutting machines In sub-section 2, Preparing, 81 pages are devoted to Carding, 73 to Doubling and Drawing, and 119 to Roving. Following descriptions of breaker and finisher cards, the size inclination and spacing of pins in the card covers are discussed at length, and some new features in card construction are described. After a general description of the drawing frame, particular makes of pushbar, chain or linkgill, spiral, rotary, and circular drawing frames are described in detail. Other items discussed are the size and spacing of pins, application of pressure and covering of the pressing roller, conductors, mechanical lifting of rollers, traverse motion, and safety arrangements. After a general description of the roving frame, the separate actions of drawing, twisting, and winding-on (including various types of differential motions) are discussed. Then follow descriptions and calculations relating to five chief types of roving frames. The section concludes with a plan of the layout of the whole preparing system, details of machinery, size of cans, and consideration of the latest methods of handling the cans.

In sub-section 3, Spinning, 93 of the 113 pages are devoted to flyer spinning. The frame is described and then particular attention paid to the component

parts such as spindle and flyer, drag, bobbins, builder motion, and so on. Particulars are given of the constructional details of five types of spindle and of a rove stop motion. Then follows consideration of four makes of spinning frame with automatic doffing motions, one with electrically-driven spindles. Ring spinning only occupies 7 pages; the principles are considered and the new Klötzer spindle with dragging hanging flyer and the Pferdkämer modification fully described. The matter on Gill spinning is confined to a description of one type of frame. The last few pages are devoted to the derivation of formulæ for the calculation of spinning production, efficiency, and wage rates.

Information is drawn from many original papers to which the full references are given. The subject matter is dealt with systematically throughout and any particular subject can be readily found. The book is well printed and bound and can be recommended to the practical man as a very comprehensive reference work to the most modern developments in machinery and also to the student for its theoretical discussions of the mechanics of the machines. L.

"Die Praxis der Baumwollwaren-Appretur." By von Eugen Ruf. Published by Julius Springer, Berlin, 1930. (Price 15 M.)

In the preface to this book the author laments the discordance between theory and practice in cotton finishing and attributes this to the attitude of secrecy adopted by the practical finisher, which makes it difficult to educate the rising generation on the right lines.

The book is therefore a causerie on practical finishing by a man claiming considerable experience, and as such makes interesting reading. The discussions range over singeing, bleaching, mercerisation, filling, waterproofing, fireproofing, and mechanical finishes, with special reference to the defects that may occur and their causes. The title of the book is misleading, as there are no detailed description of processes or machinery, nor are there any illustrations. Indeed, some modern finishes are not even mentioned. The experienced finisher would therefore be disappointed if he expected to gain any practical information from this book, but a beginner would find accounts of some of the numerous pitfalls in the way of the young finisher and may learn how to avoid them. R.G.

Handbook of Chemistry and Physics. Fourteenth edition. Compiled by C. D. Hodgman and N. A. Lange. Published by the Chemical Rubber Publishing Co., Cleveland, Ohio, U.S.A. (1367 pp. and Index. Price 5 dollars.)

This is a most comprehensive work of reference and is a lesson in value-for-money production at the price, to rival publishers. The general features and scheme of arrangement which have become familiar to users have been retained. New material, however, appears in this edition in response to requests and suggestions made by correspondents. Chief among these additions is a table of the wavelengths of the principal lines in the emission spectra of the elements produced by the arc, spark, or Geissler tube. Shrinkage conversion tables have been added to the ceramics section. Of interest, too, are tables of the transmission of ultra-violet and of infra-red radiation by various neutral and coloured glasses. A much enlarged table of indicators has also been included. The compilers are to be congratulated on an excellent production. T.

Proceedings of the Thirty-fourth Annual Convention of the American Cotton Manufacturers' Association. Published by the Association.

Despite the "domestic" character of much of this volume, information being published of interest only to or mainly to members of the Association, it also contains reports of addresses upon subjects of interest to cottonmen the world over. There is an openness and familiarity about the reporting of the speeches quite characteristic, but the picture presented is of value and interest. Subjects upon which addresses were delivered include *Cotton Commonsense*, by F. W. Shibley, Bankers Trust Co., New York; *Promoting Sales and New Outlets for Cotton Textiles*, by C. J. Callaway, of Callaway Mills, La Grange; and *Value of Research to the Textile Industry*, by R. E. Henry, of Duncan Mills, Greenville. The report is most entertaining, as it reproduces verbatim the witty speeches made during the Convention, and in this respect might constitute a model for other reports; it is not possible, however, to say the same of the amazingly "honeyed" comment on the President-elect which appears at the front of the volume. T.

Official American Textile Directory. Compiled annually by the *Textile World.* Published by Bragdon, Lord & Nagle Division of the McGraw Hill Catalog and Directory Co., New York. (1090 pp. and Index. Office edition 6 dollars.)

This Directory now combines the American Textile Directory and the American Directory of the Knitting Trade, and thus constitutes a much more comprehensive reference book for the whole trade. It must be confessed that the word "Official" in the title of the book is somewhat misleading, that being a word confined on this side almost entirely to Government and Municipal publications. The most important section of the book is that which lists "Textile Establishments in the United States, Canada, and Mexico," but little less valuable is the succeeding section which covers dealers and brokers of the raw materials of the industry; a yarn trade index; bleachers, dyers, printers, and finishers; lists of mills classified according to products—including knitting mills; and miscellaneous lists of minor divisions of the trade. The alphabetical index is most useful and rounds off a very comprehensive volume. At first sight it seemed that it would be possible to congratulate publishers and advertisers on keeping these necessary pages in their proper place—at the beginning and end of the volume—but the interspersion obsession gained the day in several instances, causing the facile use of the directory by means of its thumb-indexes to be seriously impaired. However, as these advertisement pages are only tipped in they can be easily removed, and the volume will then be found to afford very easy reference. T.

The Cotton Industry of India. Being the Report of a Journey to India by Arno S. Pearse, at that time General Secretary of the International Federation of Master Cotton Spinners' and Manufacturers' Associations. Published by the Federation, Manchester. (306 pp., 21s.)

This volume completes the series of reports compiled by Mr. Pearse on his journeys to the Continent of Europe, the United States, and to Japan and China, investigating cotton industry conditions. These four volumes constitute a very valuable piece of work upon which Mr. Pearse is to be congratulated. Taken in conjunction with the recently published Report on the Government Inquiry into the Lancashire Cotton Industry, the information available should be of very real value to those engaged in the cotton textile industry. The first fourteen pages of the book give the general impression gained during the tour and also a tabulated comparison of conditions in India and Japan. The main chapters of the report will be abstracted separately in the "Abstracts" Section of this *Journal.* T.

GENERAL ITEMS AND REPORTS

The Colour Users' Association

Eleventh Annual General Meeting of the Association, held at Blackfriars House, Manchester, on Tuesday, 15th July 1930

The following is an abstract of the main points made by Sir Henry Sutcliffe Smith, the Chairman, in his address to the Association. Sir Henry said—The Annual Meeting of this Association affords an excellent opportunity not only of alluding to the activities of the Association during the past year, but of reviewing its work since its commencement 12 years ago, and in addition, the opportunity of elaborating the incidence of the Dyestuffs (Import Regulation) Act 1920 on the colour-using trades, and of drawing attention to the progress made by the British dye manufacturers. Particular reference was made last year to the incidence of the Safeguarding of Industries Act upon such an important chemical as formic acid. The British makers are to be congratulated on bringing the price of this safeguarded product nearer to the world level and in some cases lower than the price paid by certain foreign competitors. It seems evident that since the British makers have been able to produce bulk quantities, their costs of production have been lessened, and although the price to the home consumer in the early stages of production was too high, the position now may be considered reasonably satisfactory.

The Board of Trade has renewed the exemption of oxalic acid from the safeguarded list for a further period of 12 months, in accordance with their usual

practice, but as this product is not made here it seems futile that it should come within the scope of the Act.

Dyestuffs Advisory Licensing Committee

The Board of Trade has supplied the following summary of the quantities and values of the licenses granted during the period from the commencement of the Committee in 1921 to the end of 1929—

Licenses Granted

Year	For Importation from Germany		For Importation from Switzerland		For Importation from Other Sources		Total	
	lb.	Value £	lb.	Value £	lb.	Value £	lb.	Value £
1921	671,032	197,466	1,796,754	763,299	209,719	82,056	2,677,505	1,042,821
1922	1,325,671	375,675	1,638,235	694,740	270,987	33,404	3,234,893	1,103,819
1923	1,817,571	493,499	1,412,616	459,861	461,253	36,177	3,691,440	989,537
1924	1,805,145	398,226	1,191,931	363,513	39,158	9,204	3,036,234	770,943
1925	2,175,262	334,749	1,157,270	307,754	66,522	9,081	3,399,054	651,584
1926	2,949,858	599,157	1,190,951	333,448	91,778	11,402	4,232,587	944,007
1927	3,644,152	710,938	1,230,815	306,595	115,389	16,480	4,990,356	1,034,013
1928	3,534,935	729,393	1,373,226	335,226	122,350	9,494	5,030,511	1,074,113
1929	3,899,412	743,951	1,787,796	402,788	127,069	11,385	5,814,277	1,158,124

During the last year approximately 7,800 applications have been dealt with, which is practically the same number as during the previous year, and show an increase of 15·5% over 1928. These figures are evidence of the necessity for continued research and energy in producing what the world is using. This, together with the progressive increase of production of dyestuffs in the United Kingdom since 1927, indicates that domestic consumption has increased considerably, both of British and foreign made colour. The time, however, has now come for a modification of the 1·75 factor, and this is a matter to which your Council is now directing attention. The official acceptance of a lower factor by the Dyestuffs Advisory Licensing Committee would be a mark of very real progress.

Dyestuffs Industry Development Committee

The main work of this Committee throughout the past year has been the preparation of a Report* giving a review of the operation of the Dyestuffs (Import Regulation) Act 1920 since its inauguration. In collaboration with makers and users, the Committee has drawn up a capable and exhaustive Report, which meets with the unanimous approval of its members. This Report is a fair, impartial, and accurate statement of facts. It contains many valuable statistics. At the same time it reviews the incidence of the Prohibition Act on the colour-using industries and clearly proves the disabilities to which the users have been subjected during that period, particularly in the early stages.

Bensole and Toluole

Attention was drawn last year to the importance of these items in the cost of production of dyestuffs. Despite the general fall in price of every commodity, there has been little or no decrease in the prices of benzole and toluole, which are now nearly three times the pre-war price. No doubt the increased demand for these products for use as motor fuels is one of the reasons for these high prices, but the effect of such prices in the production of textile goods cannot be ignored. I again strongly urge the manufacturers to assist the Brisish dyemakers, and indirectly the British textile trade, in their effort to regain their pre-war volume of export business. This is a case for a national view to be taken by the big industrialists concerned, and it is hoped that this appeal will be sympathetically considered.

* Issued by H.M.S.O.

Production and Export of Dyestuffs and Intermediates

From statistics furnished by the Board of Trade, a continued increase in the production of dyestuffs in this country can be reported. In 1929 the total production aggregated 55,785,032 lb. or more than six times the 1913 output. 1929 showed a substantial increase of 9·6% over 1928. The following table shows the yearly output from 1922 to 1929 compared with 1913—

	lb.	Index Figure			lb.	Index Figure
1913	9,114,134	100	...	1926	30,297,000	332
1922	20,802,563	228	...	1927	39,551,756	434
1923	33,100,719	363	...	1928	50,907,080	559
1924	33,242,704	365	...	1929	55,785,032	612
1925	32,693,402	359	...			

One of the outstanding achievements of the British makers is their increasing output of vat colours, since it indicates the growing extent to which the demand for colours with a high standard of fastness is being met. The pre-war production of dyestuffs in Great Britain amounted to 22% of the total consumption; in 1929 it exceeded 90%. It has also to be borne in mind that whereas before the war such dyestuffs as were manufactured in this country were largely produced from foreign intermediates, the quantity of intermediates it is now necessary to import is relatively unimportant, the dyestuffs manufacturers either making their own or obtaining their supplies from other manufacturers in the country.

The exports of dyestuffs and intermediates from Great Britain continue to show an increase, as the following figures indicate—

Year	Weight Tons	Value £		Year	Weight Tons	Value £
1913	2,434	177,246	...	1927	3,892	658,464
1925	5,208	847,639	...	1928	5,199	806,533
1926	3,793	614,419	...	1929	7,844	984,222

Apart from the set-back in 1926 due to the coal strike, there has been some progress during the past few years, although it is quite evident that British firms have not made headway to any great extent with the export section of their business.

Retrospective Review

It is now nearly 12 years since the Association was formed, as the natural outcome of the important Committee of Colour Users formed in 1915—called the Colour Users' Committee—at a very trying time in the history of the colour using industries. Without the pioneer work of that Committee, the great textile industries in this country, particularly in their export business, would have been seriously handicapped. The pressing need then was the production of dyestuffs to make us independent of foreign sources, and this was the basis on which this Association was formed.

It will be readily admitted no doubt that the Association has been of considerable assistance to colour users throughout the period of the Act. This was a unique form of protection—total prohibition and a licensing system for dyewares not made here and but for the guidance of the Association in collaboration collectively with the makers and the Government, the Act would have imposed too great a burden upon the colour-using industries. The operations of the licensing machinery have been carried out speedily and at a low cost, thanks largely to the voluntary assistance of its members, including those of this Association. It was through the instrumentality of the Association that a means was found of dealing with applications for dyewares on price grounds, and the factor ratio established. After considerable negotiation, in September 1922, a factor of three times pre-war level was adopted as a basis. At that time this factor was in conformity with general world prices. By progressive stages the factor has been reduced to the present one of 1·75. The reductions were as follows—

Date		Factor	
29/9/22	...	3 Times factor	
20/3/25	...	2½ „ „	(except for vat and anthracene colours)
1/7/26	...	2½ „ „	(including vat and anthracene colours)
1/9/27	...	2 „ „	
3/5/29	...	1·75 „ „	

Much work has been done by our Publicity Committee by visits to foreign countries and by making inquiries as to the prices ruling there, and with the aid of the definite information thus obtained the Association has been fully informed as to the current prices in other markets.

When the Safeguarding of Industries Act was placed on the Statute Book in 1921, it was unavoidable, by the imposition of the 33⅓% duty, that some hardship would be suffered, particularly in the early stages of the building up of the producing industries here. Your Association did valuable work at that time by means of its Vigilance Committee in its negotiations with the Government, in clarifying the position and obtaining concessions by the deletion of certain chemicals from the lists. Several items had been unnecessarily included in the Safeguarded List, which meant merely the imposition of an extra cost upon the users, and many thousands of pounds were saved by the work of the Association in having these items removed.

Another feature of the Association's activities has been the collective buying of Indigo, which at the time proved most advantageous, and by means of which preferential prices were obtained.

The Association also provided assistance to the Government in exercising its rights under the Reparation Treaty in the requisitioning of dyestuffs from Germany. The selection of colours was made entirely on the advice of our technical advisors, and the quantities specified in accordance with our estimates.

Reference must also be made to the establishment of that most useful Committee, the Joint Technical Committee, which was formed from representatives of both makers and users. This Committee was instituted following a suggestion made by your Council and has done excellent work in the preparation of graded lists of colours, contentious and non-contentious, for the assistance of the Dyestuffs Advisory Licensing Committee. The work of the Joint Technical Committee has enabled the Licensing Committee to cope with its thousands of applications in a systematic and regular manner.

Expiry of the Dyestuffs Act.

At our last annual meeting in July 1929, I again urged that the makers and users of dyestuffs should meet in a round table conference to discuss the best means of dealing with the situation which will arise at the expiry of the Dyestuffs (Import Regulation) Act 1920 in January 1931. Recently the Association was approached through the makers' official body, and certain proposals were submitted for discussion with reference to the position at the expiry of the Dyestuffs Act, and the Association was asked to meet the makers in conference. Your Council have decided to accept this invitation, but they desire that the considered views of the Association (summarised as follows) should be published—

(1) The Dyestuffs Act has achieved its purpose in assisting to establish the dyemaking industry in this country.

(2) The colour users of Great Britain have loyally honoured their pledge to assist in the establishment and development of the dyemaking industry.

(3) The users suggest that the burden of the establishment of the industry has not been equitably shared, too large a share having fallen upon them.

(4) Users are still dependent upon foreign suppliers for certain of their needs, and it would be a serious handicap if the flow of novelties and speciality dyewares from abroad were obstructed in any way.

(5) The users suggest that because of the importance and strength of the leading British dyestuffs makers and additional source of supplies from abroad now available, the serious position of 1914 is not likely to be repeated.

(6) The Government pledge to assist the establishment of the industry because of national security cannot be overlooked, but the costs should not fall solely upon the colour using industries.

I have endeavoured to give you a fair representation of the official policy of the Colour Users' Association as formulated by the Council; nevertheless, my personal opinion—as I expressed it at our last annual meeting—is still that "it would be economic folly to allow this great industry, so necessary for our trade security and now well on the way to be thoroughly established, to decline," and I

feel sure it would be regrettable from every point of view if any false step were made now which would impair the complete establishment of the dyemaking industry in this country.

Lord Melchett, in his able address at the annual meeting of the Imperial Chemical Industries Limited, the leading dyestuffs manufacturers in this country, stated that the period had been too short to enable them to catch up the long start their competitors have had, but he felt certain that, within a given time, they would arrive at any rate at an equality, if they did not even surpass the foreign makers. He made a plea for the support of the Government for a further period in the final establishment of the dye industry, because of both its national and trade importance.

The late Lord Moulton, in one of his important speeches, suggested that a period of five years' protection would be sufficient to enable Great Britain to win for itself a position in the dye industry which all nations would respect. Eventually ten years was agreed to, and we now have it on the authority of the representative of the leading makers that a still further period of protection is required, notwithstanding the admirable progress that has been made.

If, after examination by the interested parties, it is agreed that a further limited period is really necessary, then I suggest that protection should be afforded only to those dyestuffs of which the British makers have definitely established the manufacture in this country, down to the end of the existing Act. This list of colours would be scheduled as the protected or safeguarded list, and I would only include in this list, those colours which, by agreement with the users, it has been established are definitely equivalent to the best products made abroad. This would of necessity exclude those colours which to-day are the subject of controversy between makers and users. All other dyestuffs, both new and improvements on existing types, should be allowed free entry. Such a scheme as this should afford, in my opinion, adequate protection to the British makers by having a minimum of 80% of their products safeguarded, and would give them that security and confidence which would enable them to go forward in the exploration and development of newer and better products, and at the same time the British user would not be handicapped in any way as compared with his foreign competitor, in having the fullest access to the world's latest developments.

Whether the Dyestuffs (Import Regulation) Act remains on the Statute Book or not, it appears to me that there is still abundant scope for our energies as an Association to safeguard our interests as colour users in many directions.

Linen Industry Research Association Annual Report

This report marks the end of the second quinquennial period in the life of the Research Association. Reorganisation of the financial resources of the Association, involving separate support for the work on pedigree flax and fibre production by the Empire Marketing Board is noted. This has been opportune, as it enables development of the chemical, physical, and colloid sections of research work to proceed on lines hitherto beyond reach. Other steps to secure benefits and increased support are outlined but are not yet in a stage at which adjudication as to their success, or otherwise, can be made. Reference is made to the Members' Days at the Research Institute at Lambeg, and it will not perhaps be out of place here to draw attention to the desirability of all Members making an effort to send a representative. The list of topics dealt with and discussed in the period covered is wide in range and significant in character. The report records quite satisfactory progress in flax and fibre production work. A simple method has been devised for preparing thin and perfect sections of all plant fibres and fibre bundles without any complicated embedding or microtome work. This method has given excellent results and has revealed much that is new as to the structure of the cellulose fibre. Progress is also reported in the work bearing on Spinning and Weaving, and in the Bleaching, Dyeing, and Colloid Departments. A marked increase is shown in the number of samples of defective material examined and increased facilities for dealing with this work are required despite additions already made. There is a hopeful tone about the report and the future appears to hold promise of sound, well-founded development.

Canadian Industrial Agent for London

The appointment of an Industrial Agent with headquarters in London, for the purpose of attracting to Canada British branch factories, is announced by the Canadian National Railways. Mr. T. A. Hooker, the Appointee, is now in Canada investigating industrial possibilities in all parts of the country. He has already completed an extensive survey of the Maritime Provinces, Ontario, and Quebec, and is at present engaged in a similar study in Western Canada.

"It is intended," states Mr. Hooker, "to maintain in London a clearing house for all information on Canada's industrial possibilities. We will be in close and constant touch with the Chambers of Commerce and the Boards of Trade of every city as well as with our own agents. Cheap power, in the form of hydro-electric energy, a rich and expanding market in which the individual purchasing power is high, and a vast store of natural resources are factors which should appeal to the British manufacturer."

British Empire Trade Exhibition: Buenos Aires, 1931

In view of the recent sudden and complete change of Government in the Argentine, and of the uncertainty which might arise in the minds of those interested or of potential visitors, the following communication issued by the Exhibition Management may be of interest—

"The following cable has to-day been received by the Exhibition Management—

'To Follett Holt, Chairman London Committee Buenos Aires Exhibition. Accompanied by Vice-Chairman and Secretary of British Chamber Commerce and Exhibition had audience to-day with General Uriburu, Argentine Government, who received us most cordially, authorising us to state this exhibition had the approval and would enjoy the support of his Government. The Minister of Finance expressed in similar cordial terms his goodwill and desire to assist us every way possible, emphasising importance of British commercial relations with this country and quoting slogan "Buy from those who buy from us." Foregoing creates every assurance that the exhibition is not only confirmed, but will enjoy support and assistance of the Argentine Government. Conditions in this country are tranquil, business as usual. Every confidence is manifested by the public in new Government, which has now been recognised by Supreme Court.'

(*Signed*) GIBSON

Chairman, British Chamber of Commerce in Argentina."

12/9/30

THE JOURNAL OF THE
TEXTILE INSTITUTE

Vol. XXI OCTOBER 1930 No. 10

PROCEEDINGS

Lancashire Section

Luncheon Meeting at the Institute on 26th September 1930;
Mr. W. T. Boothman in the chair.

SOME IMPRESSIONS OF A WORLD TOUR

Mr. John Crompton said he wished it to be understood that he had not undertaken the tour for commercial purposes, but for pleasure. He had had the plan in his mind for the past twenty years, and the ultimate realisation of his thoughts had made the waiting worth while. His travels commenced on 5th November 1929, when he embarked at Tilbury for India. His route was the usual one, *via* Gibraltar, the Mediterranean, and the Suez Canal. His stay in Bombay was short, but he had time to visit three of the most important textile mills. He got the idea that the operatives were not subjected to very much discipline. The girls wore the national costume, which consisted of voluminous garments, and while these might be good for the cotton trade, he thought they impeded progress and reduced efficiency in their work. In one of the mills, yarn up to 60's counts was being spun, not from Indian cotton, of course, but Egyptian, and he thought that was significant.

From Bombay, Mr. Crompton went to Ceylon, and there he had the pleasure of meeting some friends from Bolton with whom he stayed over Christmas. He had his Christmas dinner on the verandah of his friends' house. He found Ceylon very interesting, and was conducted through both tea and rubber plantations. The latter industry he thought difficult and complicated, and considered that the operatives were badly paid. Ceylon was a beautiful and ancient country, and he saw several wonderful ruins, which he was told were estimated to have been in existence since 437 B.C. Wild life abounds in Ceylon, and he had the pleasure of motoring through a jungle. From Ceylon Mr. Crompton next journeyed to Australia, where he had short stays at both Fremantle and Perth, and longer visits to Adelaide, Melbourne, and Sydney. He thought that it was a great mistake on the part of the Australian Government at a time of financial stress to spend millions of pounds in transferring the capital from Melbourne to Canberra, especi ally as the former beautiful city was so suited to the needs of a capital. During his stay at Sydney he visited the famous Blue Mountains and Jenolan Caves. His general impression of Australia was that the Labour Party had not yet realised that money was not inexhaustible. A coal mine had been closed for two years owing to a dispute on the wages question, and one unemployed man with whom he got into conversation deplored the fact that unemployment pay was not provided in Australia as in England. New Zealand was next visited, and Mr. Crompton, during his stay in the islands, drove 2,500 miles, visiting the Southern Alps, which he described as a replica of the Swiss Alps and nearly always

snow-covered. He also visited the devastated region caused by the earthquake in the previous June. Nearly all the settlers in New Zealand appeared to be of Scotch origin, and he found them extremely friendly. He found that in trade New Zealand was feeling something of the world-wide difficulties. Labour in the agricultural districts was dear and scarce. He commented on the fact that few sheep were seen on the mountain sides, and he was told that grass was exhausted and it was too expensive to repasture. Many of the farmer's sons preferred to go to the towns and earn a regular wage than to carry on the home farms. Where this happened, the farms ultimately become derelict. We were all talking of economics, said Mr. Crompton, at the present time, and he suggested that each country should supply and produce what it could and exchange with the commodities of other countries. He was very much surprised by the attempts made in countries like Australia and New Zealand to build up textile manufacturing industries behind tariff walls. At a mill Mr. Crompton visited in New Zealand, 50-in. wide woollen material was being made, but the warps were no longer than 100 yards, the management informing him that their limited market did not warrant making a longer length. The cost of dyeing, drawing-in, etc., and preparing such a warp for the loom was exceedingly costly. They could prepare a warp of 1,000 yards for the same cost as 100 yards and in long as in short lengths there was always a certain amount wasted in gaiting-up the loom, hence the cost was exorbitant. This was against all the modern tendencies of mass production on an economic basis and it was his belief that such cases were the most powerful argument that could be used against bolstering up industries by high tariffs. In view of the fact that we were export manufacturers with trained and experienced labour it followed that the exchange of our finished goods for their raw materials was the natural course to prove of the greatest benefit to all concerned.

From New Zealand, Mr. Crompton cruised amongst the South Sea Islands, where he had a wonderful time. He found the island people very happy and contented, and the secret was that they were hard-working and prosperous. Each land-owner contributed an annual sum of money to a fund reserved for use in times of disease or famine.

After this, Mr. Crompton said that he went luxury travelling, visiting the Hawaian Islands and Honolulu, but he found the latter place very expensive. From Honolulu he went to California and along its coasts motored 3,000 miles. California, he said, was a magnificent country, but too much boosted. He went as far down as Mexico and had three weeks in British Columbia and Washington. He came back through the Rockies and across Canada by easy stages. During the tour he had travelled on 12 liners and slept in 68 different places.

A Joint Meeting with the Todmorden Textile Society at Todmorden, on 1st October 1930; Mr. W. W. L. Lishman in the chair.

CASE FOR RATIONALISATION IN INDUSTRY

This was the subject of a paper delivered by Mr. W. T. Shackleton, A.T.I., of Bolton.

Mr. Shackleton said that rationalisation was looked upon with disfavour by many workers because of the fear that the process would increase the volume of unemployment. It was quite probable that this would be the result at first, due in many cases to the introduction of automatic or semi-automatic machinery. There was in history a complete analogy to the present position. When power-looms were first introduced, the hand-loom weavers were so enraged that they destroyed many of them. But the march of progress would not be denied, and because of the cost-reducing effect of the power-looms the price of cloth was so reduced that the market was widened enormously, with the result that far more employment was ultimately provided. Modern organisation of industry ought to produce similar results.

In Great Britain, and in other countries to a less degree, the principle that a man has a right to live had already been conceded, and this was accomplished by what was known as social services, including unemployment insurance and the like, which, in effect, were a charge on industry. Unless we modernised our industries the burden might become too heavy. Every increase in production per worker reduced the ratio of this burden and made it more easily borne. The world was still suffering from the economic effects of the Great War. Currencies had been violently upset. It is estimated that the Great War had left the world poorer by a minimum of £70,000 millions, and the wasting of this huge amount could only result in the consumption capacity of the world being greatly reduced. He believed we were slowly but surely recovering, as the world, generally speaking, had had good harvests since the war, and it was to the land that we must look for recovery. The present phase, however, showed wholesale prices of most commodities round about pre-war prices, but retail prices of most commodities were still considerably more than pre-war prices, with the result that the agricultural peasant in India was receiving for his efforts roughly what he got in pre-war days, and was having to pay much bigger prices for his consumable commodities. Consequently, his consumption of goods was correspondingly less. By the economies of rationalised industry it should be possible to increase consumption through lower prices, as it was very doubtful if saturation point had been reached in the potential consumption of any commodity. The time-lag between wholesale price-reductions and retail price-reductions was a serious factor in to-day's industrial position. It was safe to say that retail prices would follow wholesale prices more closely under rationalisation, if only on account of the less quantity of stocks which would have to be disposed of at any one time before the retail prices could be adjusted.

The process of price-reduction was being assisted by the position of the world's supply of gold. It was estimated that world production of goods was increasing by 2% to 3% per annum, and it was very doubtful whether the world's gold supply was increasing to the same extent. Since gold was the basis of our valuation of other commodities, the effect of this was to lower the prices of these increasing quantities, unless artificial means in controlling the price of gold were adopted. When prices were being reduced, the effect was to cause stagnation in production, but, taking a long view of the situation, it must be of ultimate benefit. Industry was in a much better position from the production point of view when prices were stabilised at low levels than when they were stabilised at high levels.

Rationalisation was an effort to mitigate some of the hardships of economic laws. The individualism of the 19th century had served its day and generation, and like all other good things must end; it must give way to the co-operation of the 20th century which progress demanded.

NOTES AND NOTICES

Institute Scholarship Award

The Scholarship offered by the Council of this Institute, as first announced in our July issue, proved highly attractive to holders of the Full Technological Certificate, in relation to Cotton Spinning and Weaving, of the City and Guilds of London Institute. The Scholarship has been created as a result and under the terms of a grant from the Cotton Reconstruction Board and the Trustees of the Cotton Trade War Memorial Fund. The scheme provides for a three-years Scholarship of a maximum annual value of £175 for the first two years and £300 for the third year, the amounts to cover maintenance allowance, college fees, and travelling expenses. No less than 43 applications were received, and the Scholarship Award Sub-committee held prolonged meetings for consideration of the claims of the applicants. A number of candidates were selected to present themselves for oral examination, and, finally, the Council was recommended to award the first Scholarship to Alan Radcliffe, of Walkden, a Comber Overlooker employed by the Denvale Spinning Co. Ltd., Tonge Moor, Bolton. The successful candidate, 22 years of age, received his technical training at the Bolton Municipal Technical College, and he had followed up his general education to the extent of securing Matriculation Certificate in 1929. He has already entered upon a special course of training at the College of Technology, Manchester, as the holder of the Institute Scholarship.

Membership Subscriptions and Income Tax

The exemption from liability to income tax, sustained over many years past so far as this Institute is concerned, has been under prolonged consideration by the Inland Revenue Authorities. The cases of many similar institutions have also been considered, and in view of law court rulings which have followed decisions, the Council of the Institute decided not to engage in legal contest of the question of liability. Accordingly, agreement has been entered into with the Inland Revenue Authorities, as from 6th April 1930, to pay tax upon the surplus income of the Institute. Under the new conditions, it is assumed that members, in computing their own income tax liability, are entitled to be allowed as an expense the amount of the membership subscriptions which they pay to the Institute. This allowance is applicable to the income tax year 1930–31, and subsequently.

Institute Annual Competitions

Entries for this Institute's Competitions for the current year are now closed and the total number of competitors is 57 as compared with 55 for the previous year. There are four competitions—three in which prizes are offered for woven fabrics, and one for special yarns. The total prize money offered for the year exceeds £140. The principal competition is that connected with "The Lieutenant Harry Dent Crompton Memorial Fund." A sum of £100 is available for prizes and the competition is intended for advanced students at technical colleges and schools. The annual revenue from the invested fund is applied to the provision of prizes with a view to the advancement of the design and structure of woven fabrics. This year there are 13 entries for the principal competition, against 11 last year. In the separate competition for one specimen of woven fabric of novel character, there are 14 competitors as against 22 in the previous year, but in the further special competition, for the best single specimen submitted in connection with the Final Grade Examination of the City and Guilds of London Institute, the entries number 24 as against 15 in the previous year. The presentation of prizes for this year's competitions and exhibition of fabrics is fixed to take place on Saturday, 6th December.

Institute Employment Register

A list of members offering their services for employment appeared in our September issue. Further registrations have since been effected, and full particulars of qualifications and experience of candidates for posts may be obtained by interested employers on application to the Institute quoting the registered numbers. The following announcements refer to the additional registrations—

No. 44—Assistant Carder or Yarn and Cloth Tester in Cotton Industry. Age 27; experience on all cardroom machinery. A.T.I.

No. 45—Works Chemist (medalist); ten years' practical experience in Hosiery and knit goods trade, desires responsible post. Special experience in finishing and dyeing and in textile testing.

No. 46—A.T.I., single, age 34, experience in worsted coatings and in education in textile technology, desires appointment, preferably abroad, in either branch.

No. 47—Cotton Weaving Manager, or Assistant Manager, age 36, seeks post; 16 years' mill experience home and abroad; A.M.C.T., 1st prizewinner, Textile Institute Woven Fabrics Competition; medallist in Cotton Spinning; teaching and lecturing experience. Knowledge of Portuguese.

No. 48—A.T.I., single, age 23, seeks appointment in Cotton Mill as Undercarder. Extensive experience in erecting blowing-room machinery and cotton carding engines. Knowledge of French and German.

Institute Membership

At the July meeting of the Council, the following were elected to membership of the Institute—E. Duckworth, c/o 61 Wessex Road, Didcot, Berks. (Textile Viewer); A. E. Hyam, 17 Alma Street, Blackburn (Textile Student); A. Mills, 38 Glen Avenue, Blackley, Manchester (Assistant Clerk); G. Richmond, Ashton Bros. & Co. Ltd., 36 King Street, London, E.C.2 (Sales Manager); T. Singh, Municipal College of Technology, Manchester (Assistant Weaving Master); A. Stoppard, 47 Gunthorpe Drive, Sherwood, Nottingham (Departmental Manager).

At the September meeting of the Council, the following were elected to membership of the Institute—N. Ahmad, Cotton Technological Laboratory, Matunga, Bombay, India (Assistant Director); A. G. Babbage, 13 Berkeley Avenue, Victoria Park, Manchester (Textile Testing Assistant); H. E. Brew, 304 Liverpool Road, Cadishead, near Manchester (Textile Testing Assistant); D. Cheshire, 186 Musters Road, West Bridgford, Notts. (Works Chemist and Manager); N. Cryer, 7 Burchett Grove, Leeds (Cloth Analyst and Tester); F. Dunkerley, 31 Crossbank, Waterhead, Oldham (Spinning-room Employee); Prof. B. L. Govila, 14A Lachman Pura, Benares, India (Retired Director of Industrial and Technical Education); N. Heaton, 3 Sunny Hill Grove, Exley Head, Keighley (Assistant Spinning Manager); A. Johnson, 187 Oakworth Road, Keighley (Student); J. C. McIlveen, 360 Ormeau Road, Belfast (Technical Assistant); D. W. C. Moulton, The Bungalow, Cranbrook Road, Wimbledon, London, S.W.19 (Assistant Laundry Manager); H. R. Neill, "Kenilworth," Lisburn, N. Ireland (Technical Assistant); K. Ohata, c/o Bank of Gaiwan, 40 Old Broad Street, London, E.C.2 (Artificial Silk Manufacturer); G. G. Osborne, Lowell Textile Institute, Lowell, Mass., U.S.A. (Assistant Professor); N. W. Robbie, 227 Clippington Road, Dundee (Costing Clerk); R. J. Smith, Torridon Lodge, Headingley Lane, Leeds (Chemist); J. Styan, 29 Heaton Avenue, Neaton, Bolton (Textile Student); A. W. Swann, Woodlands, Monsell Drive, Aylestone, Leicester (Hosiery Manufacturer); S. E. Ward, J. B. Lewis and Sons Ltd., Haydn Road, Nottingham (Hosiery Manufacturer).

ADDITIONS TO LIBRARY

Since the publication of the Catalogue of the Institute's Library, in March of this year, the following additions have been made. Copies of the Catalogue can be obtained for 6d. post free, on application to the Institute.

BOOKS BY AUTHORS

Barnshaw, C.	High Drafting in Cotton Spinning. (Benn 1930).
Britton, H. T.	Hydrogen Ions. (Chapman & Hall 1929).
Bryers, T.	Practical Cotton Spinning. (Abel Heywood 1894).
Butterworth, J.	Cotton and Its Treatment in the Various Processes of Opening, Carding, and Spinning. (Hirst & Rennie 1881).
Dalton, J.	A New System of Chemical Philosophy. Parts I and II. (Weale 1842 and 1910).
Dumville, J. and Kershaw, S.	Worsted. (Pitman 1930).
Dobson, Sir B. A.	Humidity in Cotton Spinning. (Heywood 1897).
Fenn, A.	Abstract Design. (Batsford 1930).
Guest, R.	A Compendious History of the Cotton Manufacture, with a Disproval of the Claim of Sir Richard Arkwright. (Pratt 1823).
Hall, A. J.	Textile Bleaching, Dyeing, Printing, and Finishing. (Benn 1926).
Heermann, Dr. P.	Enzyklopadie der Textilchemischen Technologie. (Julius Springer 1930).
Julius, P.	*See* G. Schultz.
Kershaw, S.	*See* J. Dumville.
Kind, Dr. W.	Der Flachs. (Julius Springer 1930).
Koenig, Dr. P.	*See* Dr. W. Kind.
Lamoitier, P.	Traité Théorique et Pratique de la Filature du Coton. (1928).
Lefevre, Leon	Traite des Matieres Colorantes. Vols. I and II. (Masson 1896).
Leigh, E.	The Science of Modern Cotton Spinning. Vols. I and II. (Palmer & Howe 1873).
Muller, Dr. W.	*See* Dr. W. Kind.
Napier, J.	A Manual of Dyeing and Dyeing Receipts. (Griffin 1875).
Nonnenmacher, Dr. E.	Die Jute. (Julius Springer 1930).
Pearse, A. S.	The Cotton Industry of India. (International Federation of Master Cotton Spinners' and Manufacturers' Associations 1930).
Russel-Clarke, A. D.	Copyright in Industrial Designs. (Pitman 1930).
Sansome, A.	The Printing of Cotton Fabrics. (Abel Heywood 1887).
Schilling, Dr. E.	*See* Dr. W. Kind.
Schmidt, A.	Cotton Growing in Egypt. (International Federation of Master Cotton Spinners' and Manufacturers' Associations 1912).
Schultz, Dr. G. and Julius, P.	Systematic Survey of the Organic Colouring Matters (Macmillan 1894).
Steinbrinck, Dr. C.	*See* Dr. W. Kind.
Stiel, Dr. W.	Elektrobetrieb in der Textilindustrie. (Hirzel 1930).
Toehansen, A.	Technologisches Worterbuch. (B. Tauchutz 1905 and 1908). Two volumes.
Thom, C.	The Penicillia. (Balliere, Tindall & Cox 1930).
Wardle, T.	Power Loom Weaving of Silk Fabrics at Lyons.

LIBRARY LISTS—SUBJECTS
(Classified according to Abstracts Section)

I. Fibres and their Production

1. GENERAL

2. ANIMAL

Worsted (Pitman) J. Dumville and S. Kershaw.

3. VEGETABLE FIBRES. (b) *Cotton*.

The Cotton Industry of India (International Federation of Master Cotton Spinners' and Manufacturers' Associations). A. S. Pearse.
Cotton Growing in Egypt (International Federation of Master Cotton Spinners' and Manufacturers' Associations). A. Schmidt.

(c) *Flax, Jute, etc.*.

Die Jute (Julius Springer). Dr. E. Nonnenmacher.
Der Flachs (Julius Springer). Dr. W. Kind.

II. Conversion of Fibres into Finished Yarns

WOOL

Worsted (Pitman) J. Dumville and S. Kershaw.

COTTON

The Science of Modern Cotton Spinning (Palmer and Howe). E. Leigh. 2 Volumes.
A Compendious History of the Cotton Manufacture with a Disproval of the Claim of Sir Richard Arkwright (Pratt). R. Guest.
Humidity in Cotton Spinning. (Heywood). Sir B. A. Dobson
Traité Théorique et Pratique de la Filature du Coton. P. Lamoiter.
High Drafting in Cotton Spinning. (Benn). C. Barnshaw.
Practical Cotton Spinning. (Abel Heywood). T. Bryers.
Cotton and Its Treatment in the Various Processes of Opening, Carding, and Spinning. (Hirst and Rennie). J. Butterworth.

FLAX

Der Flachs. (Julius Springer). Dr. W. Kind.
Die Jute. (Julius Springer). Dr. E. Nonnenmacher.

III. Conversion of Yarns into Fabrics

Traité Théorique et Pratique de la Filature du Coton. P. Lamoitier.
Power Loom Weaving of Silk Fabrics at Lyons. T. Wardle.
Worsted. (Pitman). J. Dumville and S. Kershaw.

IV. Chemical and Finishing Processes

The Penicillia. (Balliere, Tindall, and Cox). C. Thom.
The Printing of Cotton Fabrics. (Abel Heywood). A. Sansome.
A Manual of Dyeing and Dyeing Receipts. (Griffin). J. Napier.
Textile Bleaching, Dyeing, Printing, and Finishing. (Benn). A. J. Hall.
Enzyklopadie der Textilchemischen Technologie. (Julius Springer). Dr. P. Heermann.
Traite des Matiérés Colorantes. (Masson.) L. Lefevre.

VI. Design

Copyright in Industrial Designs. (Pitman). A. D. Russell-Clarke.
Abstract Design. (Batsford). A. Fenn.

VIII. Building and Engineering

Humidity in Cotton Spinning. (Heywood). Sir B. A. Dobson.
Elektrobetrieb in der Textilindustrie. (Hirzel). Dr. W. Stiel.

IX. Pure Science

The Penicillia. (Balliere, Tindall, and Cox). C. Thom.
Systematic Survey of the Organic Colouring Matters. (Macmillan). Drs. G. Schultz and P. Julius.
A New System of Chemical Philosophy. Parts I and II. (Weale). J. A. Dalton.
Hydrogen Ions. (Chapman and Hall). H. T. Britton

X. **Economics**

A Compendious History of the Cotton Manufacture with a Disproval of the Claim of Sir Richard Arkwright. (Pratt). R. A. Guest.

The Cotton Industry of India. (International Federation of Master Cotton Spinners' and Manufacturers' Associations). A. S. Pearse.

Cotton Growing in Egypt. (International Federation of Master Cotton Spinners' and Manufacturers' Associations). A. Schmidt.

Copyright in Industrial Designs. (Pitman). A. D. Russell-Clarke.

LIST OF PERIODICALS

British Publications

British Association for the Advancement of Science : Annual Reports.
1929. South Africa.

British Cotton Growing Association : Reports.
1929 The Twenty-fifth Annual Report for the 12 months ending 31st Dec. 1929.
1929. Speeches at Banquet given to the Rt. Hon Lord Lloyd of Dolobran.
1930. Report by Captain Lord Stanley, M.C., M P., on his visit to the Punjab and Sind.

Industrial Health Research Board (formerly the Industrial Fatigue Research Board).
1930. A Study of Heating and Ventilation in Schools by H. M. Vernon and T. Bedford, assisted by C G. Warner

Welsh Plant Breeding Station Reports.
Grazing and Manurial Trials on Permanent and Prepared Swards and Factors affecting Seed production of Red Clover. 1930.
Experiments to test the yield and other properties of various species and strains of herbage plants under different methods of management by R. G. Stapleton and Wm. Davis 1930.

Colonial Publications (A) AFRICA

Egypt : Ministry of Agriculture Bulletins.
Technical and Scientific Service Bureau
The Soils of the Libyan Oases by R. R Le G. Worsley. 1930.
A Brief Account of the Research Work of the Sections of the Ministry at Giza. 1930.
Some supplementary records to Muschler's Manual Flora of Egypt by N. D. Simpson. 1930
The Angular Leaf Spot of Cotton in Egypt by T. Fahmy 1930.
A Note on Two Marssonina Diseases on Willows by R. M Nattrass. 1930

Kenya : Department of Agriculture, Nairobi.
Agricultural Census. Tenth Annual Report (1929).

Nyasaland Reports : Department of Agriculture, Zomba.
Annual Report. 1929.

Uganda : Department of Agriculture.
Report of the Commission of Enquiry into the Cotton Industry of Uganda. 1929.

Union of South Africa.
Bulletins.
Poisonous Plants of South Africa by S M. Stent. 1929.
Artificial Silk and its Relation to Wool, Cotton, Mohair, and Silk by J. L. Servontein. 1929.
Merino-Wool Classing by P. D. Rose. 1930.

(B) AMERICA.

Barbados : Department of Agriculture.
Annual Reports for 1928-1929.

(C) ASIA.

Assam : Department of Agriculture.
Annual Report of the Department of Agriculture for the year 1928-1929.
Report of the Civil Veterinary Department, Assam, for the year 1928–1929.

Bombay : Annual Reports of the Department of Agriculture in the Bombay Presidency. 1929.
Report on an Inquiry into Wages and Hours of Labour in the Cotton Mill Industry 1926. 1930.
Memorandum from the Government of Bombay. 1929.

Bulletins of the Agricultural Research Institute, Pusa.
List of Publications on Indian Entomology, 1928. 1929.
A Contribution to our Knowledge of South Indian Coccidæ by T. V. R. Ayyar. 1930.
A New Method of Estimating Total Carbonates in Soils by A. N. Puri. 1930.
List of Publications on the Botany of Indian Crops by F. J. F. Shaw and R. D. Bose.
Sorosporium Paspali McAlp on Paspalum scrobiculatum L., Kodra Smutby A. Sattar. 1930.

Indian Central Cotton Committee.
1930. A Comparison of Some Methods of Testing the Breaking Strength of Single Cotton Fibres by H. Navkal
1930. Studies in the Sampling of Cotton for the Determination of Fibre-Properties. Parts I and II by R S. Koshal and A. J. Turner.
1930. The Weight per Inch of Fibres of Different Lengths, and the Numbers of Fibres of Different Lengths per Seed, for each of the Standard Indian Cottons by R. L. N. Iyengar and A J. Turner
1930. Preliminary Spinning Tests on Mixings of Indian and American Cottons. Using Ordinary and High Drafts by R. P. Richardson and A. J. Turner.
1930. Technological Report on Banilla Cotton. 1924–1930.
1930. The Foundations of Yarn-Strength and Yarn-Extension. Part III by H. Navkal and A. J. Turner

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Georgia Experiment Station : Department of Agriculture.
1930. Forty-second Annual Report, for the year 1929.
1930 Cotton Variety Tests, 1929, by G A. Hale and H. K. Brabham.

Michigan Agricultural Experiment Station.
1930. Quarterly Bulletin.

North Carolina : Agricultural Experiment Station.
1915 Report on Variety Tests of Cotton for 1914 by R. Y. Winters
1920. The Cotton Boll Weevil by F. Sherman
1923. Dust-Poison Method for Control of Boll Weevil by F. Sherman

United States Department of Commerce.
(c) *Simplified Practice. Pamphlets*
1929. The Commercial Standards Service and its Value to Business.
1930. Men's Pyjamas (made from Woven Fabrics)
Scientific Papers
No 559 A Burette for the Accurate Measurement of Gas Volumes without Gas Connection to a Compensator by E. R Weaver and M. Shepherd. 1927.

United States Department of Agriculture.
Technical Bulletins.
1928. Factors Affecting the Price of Cotton by B B Smith No. 50.
Farmers' Bulletins.
1930. Index.
No. 1268. Sheep-Killing Dogs by V. L. Simmons. 1929.
No. 1273. The Stock-Poisoning Death Camas by C. D. Marsh. 1929.

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Bombay Textile and Engineering Association. Prize Essay 1929 by S. K. Khan.

Department of Scientific and Industrial Research.
Report of the Water Pollution Research Board for the year ended 30th June 1929.
Second Report of the Fabrics Co-ordinating Research Committee, 1930.

General Federation of Trade Unions.
Report on the Effect of Taxes upon Prices, 1930.

Hilgardia. The Medullated Wool Fibre by J. F. Wilson, June, 1929.

Histological Study of the Integument of the Armadillo Tatusia Novemcincta by Z. K. Cooper, 1930.

Imperial Department of Agriculture for the West Indies.
A Note on Resistance to Black Scale in Cotton by S. G. Harland.
Studies of the Transport of Nitrogen in the Cotton Plant. Parts I, II, and III by E. J. Maskell and T. G. Mason, 1930.

Imperial Institute. Annual Report. 1929.

Influence of Moisture on the Strength and Elastic Properties on Cotton Yarn by C. F. Goldthwait.

International Chamber of Commerce. Uniform Regulations for Commercial Documentary Credits.

Memorandum on the Packing and Grading of East Indian Hemps by A. Wigglesworth.

Mildew in Cotton Cloth and Some of its Causes by Percy Bean.

Register of Patent Agents printed under the direction of the Chartered Institute of Patent Agents. February 1930.

Report of the Manchester Committee on Cancer for the year ending 31st October 1929.

Structure of Cellulose Gel (Japan). I. Mechanism of Gelatin and II. Syneresis of Viscose by K. Atsuki and H. Sobue.

Structure and Elastic Properties of the Cotton Hair, by F. T. Peirce.

LIST OF SYLLABUSES

Paisley Technical College.

MISCELLANEOUS PUBLICATIONS AND WORKS OF REFERENCE

Carding and Spinning Master's Assistant; or the Theory and Practice of Cotton Spinning. Glasgow. J. Niven. 1832.

A Century of Fine Cotton Spinning, by McConnel & Co. Ltd. 1790–1906.

City and County Borough of Belfast. Memoranda as to Meetings of the Council and its Committees. 1929–1930.

Subject List of Works on the Textile Industries and Wearing Apparel including the Culture and Chemical Technology of the Textile Fibres in the Library of the Patent Office. 1919.

Technologisches Worterbuch. 2 Volumes. (B. Tauchutz). A. Toehansen. 1905–1908.

REVIEWS

Copyright in Industrial Designs. By A. D. Russell-Clarke, of the Inner Temple, Barrister-at-Law. Sir Isaac Pitman & Sons Ltd., London. (Price 10s. 6d.)

The author has ample justification for presenting this volume in view of the statement that twenty-two years have elapsed since a book was last produced on this subject. Since then, many changes have occurred and a considerable number of important cases have been decided in the courts. Moreover, the Copyright Act of 1911, by Section 22, excludes from the protection of ordinary copyright anything which is capable of registration as a design. The Patents and Designs Act of 1919 introduced a new definition of a design, and the author expresses his belief that it is extremely important that it should be realised what sort of things are suitable and what sort are not suitable for registration. Various aspects of the process of registration and the protection secured thereby are discussed, and the work should appeal to the industrialist—particularly the textile manufacturer concerned with design in relation to fabrics—as well as to the law student. The book provides full information as to procedure in regard to registration. T.

The Successful Management of Cotton Mills. Its Modern Methods. By Henry D. Martin. Published by Ranchhodlal Amratlal, Sankdi Sherry, Ahmedabad, India. (583 pp., price 7s.).

The Publisher's Note informs us that this work was first published in two separate volumes, each with a different title. This is the probable explanation of the amount of duplication to be found in the book. There are no less than twelve sections which are duplicated, sometimes even to the title, although in other cases there are slight differences in the titles. Thus, "How to Maintain Production" (pp. 100-104) is to be found again under "How to Give Satisfactory Production" (pp. 329-333), and "The Proper Method of Keeping Numbers in a Cotton Mill" (pp. 202-213) becomes "How to Keep Sizes of Yarn Right" (pp. 518-529). In one instance the whole of an article of twelve pages is repeated in another part of the book, and in another case of repetition the article occupies fifteen pages. Altogether over 70 pages are duplicated in this way.

Some of the matter in the book was originally published in various trade journals, during the years 1904-09. In other cases no dates are given, although

expressions such as "Coming down to present day affairs, there are some cotton mill booms in force" (p. 439), and several references to technical matters belie the sub-title. On the other hand, of course, there is much in the book which is as true to-day as it was fifteen or twenty years ago. There are many generalisations of the type "the machine should be properly oiled and cleaned" which are really not very helpful. There is also a lack of scientific precision throughout the book. The chapters on yarn testing and on uneven yarn are especially lacking in this respect.

There is an interesting comparison between the cost of production in carding, spinning, preparation, and weaving processes of old machinery and new (p. 191), but unfortunately no information is given as to the age of the old machinery, nor any details of the differences in the two sets of machines.

Useful information is to be found in the book, but it is frequently hidden amongst unnecessary verbiage, for the book is written in a very discursive manner. This style may appeal to some readers, but is usually exasperating to the earnest student. especially when, as in the present instance, there is no index to the work. Apart from the duplication referred to, the book could have been curtailed with advantage by the avoidance of redundancy. W.E.

The Printing of Textiles. By Reco Capey. Published by Chapman & Hall Ltd., London, 1930. (138 pp., price 13s. 6d.)

This volume is apparently written with a view to aiding the creative designer of "Printed Textiles for commercial application," and also of fostering the aesthetic qualities which are usually found in individual work. It does this by giving, to students of design, such formulæ as are necessary to enable them to experiment in the actual materials and dyestuffs for which their designs are intended, and also to the artist craftsman who is desirous of expressing himself through the medium of this craft in studio productions. Although Mr. Capey's book is not a large volume, it contains a selection of essentials, which, though tightly packed, are lucid and complete. The "Chemistry" side of printing, which is usually the bugbear of the prospective experimental printer of textiles, is found in this book in simple and concise recipes, which will make the production of fixed printed dyes a simpler process than perhaps thought possible. Besides the help given in the printing processes, a section of the book is devoted to the development of the textile printing craft from the earliest times and traces its progress from the Eastern to the Western Hemisphere. To supplement this there is a series of photographic illustrations, whilst in other sections are to be found several examples of printed fabrics by the author himself. Other illustrations, indicate the tools, materials, and other accessories which would be necessary to enable the work to be done most satisfactorily. The dyeing and printing of "Artificial Silk," I think, should have had mention in an up-to-date work on textile printing, but perhaps Mr. Capey considers the processes involved to be too intricate for the beginner. However, such information as it gives should be adopted and used by all who are interested in, and appreciative of, the qualities of refinement and culture to be found in the craftsmanship of earlier periods. It certainly should find its way at once into the experimental studios, and school workshops, where no doubt it will be kept on the work-bench and in continual use. P.O'B.

Organisation in the Cotton Trade—The First Step. By F. Greenhalgh. Published by John Heywood Ltd., Manchester. (40 pp. 1s. 6d.)

The present publication summarises and amplifies the arguments for a standard system of costings, which the author adduced in his "Trade Organisation—Cotton Spinning."* Though he rather exaggerates the benefits likely to accrue from standard costings, though he underestimates the real obstacles to the adoption of his plan, and though he is inclined unjustly to disparage existing methods of costing, he has nevertheless given something of real value to the cotton trade.

The section devoted to the Cotton Report of the Government Inquiry shows commendable caution. The plausible recommendations of that report are not to be accepted at their face value. When the author of this work refers to the fact that the Government Inquiry could find (in their opinion) no indisputably reliable costs, he makes a strong point for the adoption of his standard system. E. E. C.

* See the Review in this *Journal*, Vol. xxi, p. 130.

GENERAL ITEMS

Textile Education—Short Course for Teachers

In continuance of its already successful policy of holding short Summer Courses for Teachers in Technical Colleges, Schools of Art, Evening Institutes, etc., the Board of Education again arranged a comprehensive series for 1930. Of chief interest was that in Textile Subjects, held from 21st July to 1st August in London.

As on previous occasions, those in attendance were chosen from applicants engaged in teaching subjects (either trade or ancillary) in textile courses relating to Cotton, Wool, Worsted, Silk, Hosiery, or Lace. The course was conducted by Mr. J. E. Dalton, H.M.I., assisted by H.M.I.'s Mr. Wilson and Mr. Salt, and was as successful as it was useful and enjoyable.

A lecture-room and a temporarily equipped testing-room were provided at the Westminster Technical Institute. Here the work consisted mainly of General Textile Technology in various aspects and bore reference to school curricula and to the conditions laid down by the Textile Institute for the award of its Associateship. This portion of the work was conducted by Professor W. E. Morton, of Manchester College of Technology.

Practical work in Microscopy formed an important part of the course and was directed by Mr. H. B. Lacey, Head of the Natural Science Department, in his laboratories at Chelsea Polytechnic. Some trial made of photographic work in association with that in microscopy proved successful and indicative of further development.

Visits were arranged to South Kensington Science Museum, to the Home Office Museum, and to the Imperial Institute. The courtesy of the authorities in permitting and organising these events was much appreciated. The social event of the course was a charabanc outing to Windsor.

Special lectures were arranged in addition to the routine courses and were delivered as follows—On "Hints to Technical Teachers," by H.M.I. Mr. Wilson; on "Woollen and Worsted Dyeing and Finishing," by Mr. J. B. Speakman, Leeds University; and on "Cotton Dyeing and Finishing," by Mr. F. Scholefield, College of Technology, Manchester. The course terminated with a general discussion on the work completed.

Through the kindness of the authorities of the Westminster Training College, hostel accommodation was provided at the College in Horseferry Road, familiar to many as the Headquarters, during the war, of the Australian Expeditionary Force. The College affords every opportunity of rendering the domestic and social side of the course agreeable and those who thus temporarily resumed their studentship found much of the enjoyment due to their surroundings.

Drapers' Company's Research Scholarship in Dyeing

Applications are invited for the above Research Scholarship, tenable in the Dyeing Department of the Technical College, Huddersfield. The object of the scholarship, which is of the value of £100 a year with remission of fees, is the encouragement of original research upon matters of interest to the dyeing, finishing, or other section of the textile industry. Further particulars and forms of application may be obtained on application to the Principal of the Technical College, Huddersfield.

British Empire Trade Exhibition, Buenos Aires, 1931

The London Office of the British Empire Trade Exhibition, Buenos Aires, 1931, has received a cable from Buenos Aires stating that the new Argentine Government has consented to issue an official decree giving protection to all patents, trade marks, etc., unregistered in the Argentine, for a period of six months and covering the duration of the Exhibition. Patents and trade marks belonging to exhibitors have so often been the subject of piracy by unscrupulous persons, prior to such exhibitions, that the value of this concession by the Argentine Government is incalculable to exhibitors and intending exhibitors in fully protecting their interests, and the goodwill wrapped up in trade marks, brands, etc. As a token of goodwill towards the Exhibition and a desire to further trade relations between the two countries, no finer gesture could be made by the new Argentine Government, whose attitude towards the British Empire Trade Exhibition appears even more benevolent than that of its predecessor.

THE JOURNAL OF THE TEXTILE INSTITUTE

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PROCEEDINGS

Lancashire Section

Meeting at the Institute, Friday 3rd October, 1930, Mr. Frank Wright presiding.

TEXTILE SPECIFICATIONS AND THEIR PREPARATION

The Chairman, who expressed regret that the Chairman of the Lancashire Section, Mr. W. T. Boothman, was unable to be present, called on the lecturer, Mr. James Smeaton, F.T.I., to give his address.

Mr. Smeaton said that during recent years there had been a very considerable increase in the use of specifications in the purchase of textile supplies. The Chamber of Commerce Testing House had, during the past three years, prepared no less than 400 such specifications. Another indication of the magnitude of this work was furnished by the statement that fabric to the value of £100,000 had been inspected to one specification alone. In the preparation of specifications, said the lecturer, first consideration should be given to the actual requirements of the buyer together with an appreciation of the general limitations of textile materials. The "particular purpose" for which a fabric was required was the prime controlling factor. Neglect of this often entailed "overloading" the specification with unnecessary detail, with resulting increases in cost of materials.

All specifications, he continued, should clearly indicate the methods of testing to be employed in determining their various requirements and, when necessary, the conditions of the material when the determinations are made. Bearing in mind the skill and experience of those by whom the testing and final adjudication will be made, it is essential that tolerances be laid down for the specification in every detail. In specifications for both yarns and fabrics it was advisable, said the lecturer, to refer to a standard sealed sample, since there were many characteristics, such as colour, handle, regularity, freedom from faults, which could not adequately be expressed in the terms of a specification. Mr. Smeaton then discussed the various points to be observed in connection with specifications for Yarns and dealt successively with description, quality, colour, regularity, moisture content, counts of yarn, strength, turns per inch, and other special requirements such as the percentages of different fibres in mixture yarns. He then turned to specifications for Fabrics and dealt therein with the quality; colour, including class and fastness of dyes employed; measurements, such as width, length, and weight; threads per inch; thickness; counts and twists of yarn; strength; shrinkage; and manufacture. In all instances definite particulars were given and slides were shown giving tabular records and photographs of yarns and fabrics exhibiting special qualities. Finally a few "type specifications" were shown, such as a specification for a "Grey Cotton Twill Sheeting," "Cotton Bath Mat," and for a "Cotton Canvas." Concluding, Mr. Smeaton said it had not been his object to lay down any ideal method of preparing textile specifications but rather to indicate commercial practice as it existed to-day.

Discussion

Following the lecture, the Chairman, Mr. Frank Wright, said that although he was a spinner and not a manufacturer, he had been extremely interested. Mr. Smeaton had told them what specifications were and how they were tested.

Mr. W. P. Crankshaw said it occurred to him that most manufacturers were chary about inspection. Specifications fulfilled two purposes—to enable the buyer to find out what he wanted and how to expect delivery. In the old days samples two yards long were not supplied; in fact, on occasion he had had samples no bigger than a postage stamp. He was glad the lecturer had agreed that though some things could be tested mechanically, there always remained that indefinable factor—quality.

Mr. Benjamin Hesketh said he was interested in the question of shrinkage and asked what was a reasonable amount.

Mr. Smeaton said that in the usual run of drills and twills a shrinkage of about 2% in either direction, after soaking, was not unreasonable—say 2% in warp direction and 3% in weft.

Mr. J. Redman asked why some specifications for the testing of strength of a fabric gave a definite traverse of the moving jaw whilst others stated a breaking load.

Mr. Smeaton said this was left to the discretion of the people who drew them up, some preferring one method and some another.

One member stated that his firm had sent some dyed yarns to Australia to be made up into towels which on arrival were tested, and then returned as not being commercially fast. They were tested on return and found to be commercially fast. Should there not be some definite statement as to the term.

Mr. Smeaton said that the problem was now being investigated and there would shortly be specific terms, but in the meantime it could only be a question of opinion.

Another question referred to how often "crimp" was specified. It was difficult to state ends and picks per inch as one result could be obtained when the cloth was in the loom and another when it had been taken out. Should not "crimp" be given ?

Mr. Smeaton said that "crimp" was frequently specified in fabrics for the rubber industry, but he thought it would be preferable to specify it in many other types of fabrics.

Mr. Crankshaw in moving a vote of thanks said he thought Mr. Smeaton should be asked to repeat his lecture in other manufacturing districts.

Major Vernon in seconding said he had recently returned from India and was, therefore, particularly interested in the points raised by the lecturer in regard to humidity as it played a most important part in the mills of that country.

Mr. Smeaton in acknowledgment said perhaps he had not made it quite clear that all tests made at the testing house were carried out at constant humidity.

Joint Meeting with the Burnley Textile Society at Burnley, on Tuesday, 21st October 1930, Mr. Luke Thornber presiding.

MONETARY POLICY AND THE COTTON INDUSTRY

Mr. Thornber, introducing Mr. E. E. Canney, M.A., the lecturer, said he was anxious to hear what Mr. Canney had to say, as, in common with many others, he was on the look out for anything that would be of benefit to the cotton trade. He then called on the lecturer, reserving his own remarks until afterwards.

The people of this country, said Mr. Canney, should know the pressing need for monetary reform. They should know that money scarcity lies at the root of their troubles and uncertainties. They should know that still greater dangers await them from an unreformed monetary policy. Though the clouds over the country and over the cotton industry in particular would not move of themselves,

the will of the people, bravely and intelligently facing the problem, could undoubtedly soon restore prosperity, for on such fundamental reforms, as are needful, Governments are not likely to take action without express instructions to do so. In this movement it devolves upon the employers and wage-earners in the cotton industry to take the lead. Their industry is specialised as an exporting industry, and is, therefore, more injured, than any other, by the consequences of money scarcity.

Money scarcity forces down prices. Wholesale prices feel the effects first; and retail prices inevitably lag far behind. A disparity between wholesale and retail prices is thus produced, which is not only symptomatic of the economic *malaise* that now afflicts the world, but is also followed by serious consequences.

The consequences of declining wholesale prices and an increasing retail disparity, are as follows—Taking the present levels in Great Britain as typifying those of the world, we find that the producers of raw materials and semi-manufactured products are at present receiving about 118% of pre-war prices. When, as consumers, they come to purchase their daily necessaries they have to pay 157% of pre-war prices. The producers of many finished manufactured products are in the same case. So also are the world's unemployed and under-employed; all forced to under-consume.

Instead of the world's producers competing for a 100% of steadily increasing consumption, they find themselves desperately fighting for a share in a 70 or 80% of declining consumption. Hence many deleterious reactions, which aggravate the consequences of the primary evil, gold scarcity. Moreover, large-scale manufacture and agriculture, during times of enforced decline in wholesale prices, are practically helpless in their efforts to bring costs down in proportion. Costs also lag behind; wholesale prices become less than costs, and bankruptcy ensues. Assuming that wage-earners preserve nominal wages at the retail level, they are unconsciously forced to conspire with the general circumstances (arising from money scarcity) that destroy their industries; but whatever advantage they may appear to have, out of wages higher than their industries can support, they have to hand over when they come to meet their personal expenses at the retail level of prices. In ever-increasing numbers as their industry declines, they are thrown into the ranks of the unemployed and become under-consumers.

As long as Great Britain fixes its currency at its present gold price, and because the natural, political, and social influences of the world, together with the flight from silver, are all against an effective world economy of gold; the general tendency of prices must be downward for years to come, and bankruptcy and unemployment must increase in volume.

The present depression was a repetition of past experience. Gold and silver scarcity were mainly responsible for nearly 30 years of blackest depression after the Napoleonic Wars; and monetary reform was one of the great political issues of the day. Relief came with gold discoveries in California and Australia, which produced a tenfold output of gold in the years 1853–1862, as compared with 1831–1840. On the whole, the years 1846–1873, were of unprecedented prosperity and the movement for monetary reform subsided. Following the Franco-Prussian War, many countries in rapid succession transferred from either the silver or the bi-metallic standard, to the gold standard, and this movement, together with declining gold output again involved the world in the evil consequences of specie scarcity. This depression was world-wide and lasted about 23 years. Thence arose another movement for monetary reform supported by many Governments as well as by producers and economists throughout the civilised world. Relief this time came from the Rand and Klondyke, where gold discoveries increased world output four-fold over the period 1890–1910. Reasonable prosperity was thereby restored and the movement for monetary reform again died away. Relief to the present depression could not possibly occur in the same

way again, and therefore, the movement for monetary reform would not again be suppressed.

It is authoritatively accepted that world production increases at the rate of 3% per annum. In order to ensure stable levels of prices, it is necessary that the annual output of specie keep pace with this increase in production. But the output in 1929 was at least 45% short of requirements. Largely owing to silver's decline in gold price, i.e. reducing its effectiveness as the complement to gold, the output for the present year is 50% short. If the world continues to utilise specie the way it now does, at least three times the present output will be required in the year 1940—an absolute impossibility. Gold output is definitely declining.

It was therefore desirable, said the lecturer, that those who understand the question and those employers and employees in our basic industries, who were apprehensive of the future, should come together. The part of the cotton industry at this moment, as he conceived it, was to impress upon reformers the supreme urgency of quickly coming to a common agreement as to policy; to make a common cause with agriculture and all other industries; to spread instruction by every means in their power to every home throughout the land; and thus to continue until reforms were put upon the Statute Book.

Some discussion followed Mr. Canney's address and questions were asked in reply to which Mr. Canney stated that it was a fundamental misconception that gold was an invariable standard. A yard measure, or a pint pot, were stable and could be used anywhere but there was not at the moment any similar stability in connection with gold; it was subject to the laws of supply and demand and our trade was being increasingly injured by its scarcity and misuse. A hearty vote of thanks to the lecturer concluded the meeting.

Yorkshire Section

Luncheon Meeting at Bradford, Thursday, 23rd October 1930, Lt.-Col. B. P. Dobson in the chair.

THE TRADE OUTLOOK

The Chairman said that as President of the Textile Institute it was his privilege to welcome the Rt. Hon. William Graham, M.P., President of the Board of Trade. It was a particularly opportune time for a President of the Board of Trade to address the Institute, that they might hear from him some remarks on the future of trade in this country. Many of them were inclined to be pessimistic as to the future, and never in the lifetime of the present generation or in the memory of the previous generation had industry generally experienced such a disastrous time. No doubt many present were hoping to gain some further light on the problem from Mr. Graham, who had just been in Lancashire with his colleague, Mr. Clynes, endeavouring to devise some means of lifting the cotton industry of Lancashire out of the dreadful depression in which it now found itself.

As the Minister who had charge of the trade of the country, they looked to Mr. Graham for advice with regard to new facilities for improving trade, better means of utilising the present machinery, and methods by which all those who were engaged in industry, whatever their political opinions or whatever class of industry they might represent, could pull together to put the trade of the country on its feet again.

Mr. Graham said it was a very real pleasure, amidst great pressure of public work, to come to Bradford and speak very briefly indeed on some of the large questions in which his audience and he were commonly interested. The time at their disposal was limited, and he proposed to plunge at once into some of the considerations which immediately confront anyone who holds office at the Board of Trade and is anxious to make some kind of contribution to British industrial recovery. As the Chairman had indicated, each had his own political party and wide views were held regarding the future of the industrial structure in Great

Britain, but the views of every party were bound up with a general industrial recovery, because it was idle to discuss industrial structure if this country were to decline in the markets of the world and to sink to an inferior status.

We were beginning to find out now, in almost a dramatic form, the real burden of the war. That vast world-strife cost this country between £10,000,000,000 and £11,000,000,000, and it left us with a great heritage of debt. It was a fact to keep in mind, without in any way belittling the contribution of other lands, that a disproportionate part of the burden fell upon Great Britain and was settled upon the 44,000,000 of our people at the present time.

There was one further consideration which was strongly impressed upon the Chancellor of the Exchequer and himself while they were engaged at the two Reparation Conferences at the Hague. It was a profound error to suggest that we were getting any reparation payments in Great Britain. This country is merely a channel through which these European contributions year by year pass to the United States of America. It is quite true that the obligation is not linked up in fact in the way described; but in effect that is the way that these payments flow. So whatever view was taken of the past that vast obligation, aggravated unfortunately by nine or ten years of profound industrial distress, remained.

All parties had, in the post-war years, been trying to deal with this problem, continued Mr. Graham, and his Government had battled with very much the problems with which their predecessors had battled, with this difference, that since October and November of last year the position had been aggravated beyond all recognition by the great downward slump in prices. The question which he and great industrial leaders were asking themselves from day to day was whether there was any sign that rock-bottom had been touched in wholesale commodity prices, any sign of that upward movement which would give confidence to industry and commerce and make a large immediate diminution in the tragic figures of unemployment.

Was there anything in the point which was made by many critics at the present time, said Mr. Graham, that we were suffering by reason of a too precipitate return to the gold standard and to some extent from a mal-distribution of world gold as the basis of industrial and other credit? We all recognise that there must be some anchorage for the currencies of individual countries and through that anchorage some kind of order in the foreign exchanges as the basis or at all events the vehicle of the world commerce in which we are commonly engaged; but he sometimes thought it was probably true that we had made too speedy a return to the gold standard, and that this effort to get the pound and the dollar to look one another in the face added another form of sacrifice to the already very considerable sacrifices which the millions of people in this country had made. He was no inflationist, and he did not believe there was any remedy in inflation. Return to the gold standard was made in 1925, and the object was to get stability in foreign exchanges, because the dislocation in the heart of Europe and in Germany and other countries was having a very bad effect on important sections of our export trade and on European recovery. The step was taken, and the exchanges were stabilised. We went back, substantially, to a pre-war parity; but other countries, stabilised in terms of an appreciation, had written off a great deal of their internal indebtedness, and had profited by that extinction of debt in their industrial operations. We knew that that had accentuated their competition and made it more difficult for this country to regain its place in the markets which these other countries entered while our hands were tied behind our backs or while we groaned under the immediate load of that post-war burden.

But there was one consideration which was of importance at the present time, which, he urged, was not merely an academic proposition. It was our duty to bring our industrial and other experience to bear upon our political representation and to see that the two marched together in some kind of programme of commonsense, at all events for the purposes of industrial recovery.

This mal-distribution of gold at the present time had occupied the minds of many of our leading business men and some of the ablest students of that problem. The post-war concentration of gold in the United States was well known, as was the very large concentration in France within recent times. The question arose as to whether that concentration had so reduced the amount available as the basis of credit in other spheres as unduly to restrict the credit which should have been forthcoming for sound business enterprise and contributed to the further fall of the price-level, and therefore knocked the heart out of still another section of British industry and commerce. He thought there was no doubt that the mal-distribution has contributed, within limits, to a part of the price fall, and accordingly the next report of the Committee of the League of Nations on gold, which is expected very soon, is designed to direct its attention to remedies and to see what can be done through the central banking institutions—which after all were the custodians of the reserves in the different countries—to work out some kind of a programme. After all it was very unfair to all sections of industry and commerce and very unfair to the millions of workers in all these industries to have their efforts thwarted or to have their confidence undermined by something in the credit structure of the world which was beyond their control but which had a profound influence on their operations. Continuing, Mr. Graham referred to one controversy which was growing increasingly in our midst. It was said that we were never going to recover our export trade. There was the new production in India, in Japan, and to some extent in China. There was the express determination of the Dominions to build up their own manufacturing industries, side by side with their primary agricultural and raw material industries, and only to admit so much of the manufactures of other countries as was not inconsistent with that domestic development. These were great world changes, and we had to recognise them. But surely we could never take the view that even all that development meant that this country was to sink to an inferior place as an exporting nation. About one-half the 1,900 million people in the world is in three areas—India, China, and Russia. There you had hundreds of millions of people whose material needs had not been satisfied, and to whose improved demand British industry and commerce should in due course be able to make a powerful response in the output of its goods.

Mr. Graham next referred to the importance of the home market. There was much all could do to stimulate demand within our own country. But when we had said the most we could say for that, it remained true that we have to export a large quantity of our goods overseas. At the present time we do two-thirds of our trade with countries outside the Empire, and the process of adjustment, if adjustment there was to be, must be carefully undertaken.

In all these industries, asked Mr. Graham, what was the central proposition that we had to face? It was this: "Can we compete at world prices and regain those markets in whole or in part and provide employment for the millions of people now out of work and thus rebuild the position of this country?" He was hoping that we should soon begin to see an upward movement in commodity prices. It seemed incredible that they could very long continue their downward trend when certain basic commodities were actually below the pre-war level. But there was a bewildering variety of other considerations. He did not disguise that it was a highly controversial issue, but it was undeniable that we should all lose together if there should be any large-scale conflict in the adjustment of wages or hours of work or conditions of labour; and he hoped from the bottom of his heart that we might be capable of some policy which would avoid a conflict of that kind. There was this great question of rationalisation and the problem of trying to build up new industries to absorb the displaced labour in certain trades which could not carry their personnel if they were going to survive in home or in world competition. Our broad industrial problem in this country was to see how far this displacement in the north and in these fixed industrial centres was

going to be made good in the newer industries either there or more probably south of a line from the Wash to Bristol, where conditions in taxation were perhaps a little easier than they were in the industrial fields which had borne the burden of the distress.

Finally, said the speaker, he would like to think that we were approaching these problems together in a constructive spirit. He knew that there was a great fundamental controversy regarding the future of our industrial structure. But whatever the ultimate decision, there were these immediate considerations which were fundamental to any industrial structure, which he hoped and indeed knew that they were going to study together.

Mr. John Emsley, in proposing the vote of thanks to Mr. Graham, said he was not a defeatist, and he did not believe that England was down and out. The conditions that appertained in the worsted industry of England appertained in every country in the world to a greater or less extent. The industry was suffering like all other basic industries, from the phenomenal decline in the value of raw materials. He had very great pleasure, on behalf of those present, in thanking Mr. Graham for the very lucid manner in which he had spoken.

Mr. Arthur Saville, in seconding the motion, said that, as Chairman of the Yorkshire Section, he wished to say how much the Yorkshire members of the Institute appreciated the visit of Mr. Graham.

The vote of thanks was carried amidst applause.

London Section

Meeting at the Clothworkers' Hall, London, on 27th October 1930
Mr. F. Henley presiding.

FLAX, JUTE, HEMP, AND OTHER, LESS-KNOWN, FIBRES

The Chairman introducing the lecturer, Mr. E. Wigglesworth, said that he was undoubtedly an authority on the subject upon which he was going to speak. It had been difficult to get the film from Belgium which would be shown at that meeting and it had actually not arrived until 4 o'clock. They were under a distinct obligation to the Royal Society, for the help they had rendered in getting it through the Customs and to the officials for facilitating its arrival on time. The efforts of the Section were directed to bringing the manufacturer and distributor together, as far as possible, so that by a combination of effort they might mutually help all sections of the trade. The Section Committee would welcome a memorandum from the distributors of their difficulties so that through lectures given by experts any questions raised might be answered. He had much pleasure in introducing the lecturer.

Mr. Wigglesworth said that in the popular mind "textiles" comprised cotton, wool, and perhaps silk, but that there were other fibres such as flax, hemp, jute, etc., in which he hoped to arouse an interest on this occasion. From Board of Trade returns for 1926–1927–1928 the average annual imports of fibres retained for consumption in the United Kingdom were, in round figures, as follows—

Cotton	660,000 tons ...	value £69,500,000
Wool	218,000 ,, ...	,, £36,000,000
Jute	181,000 ,, ...	,, £6,000,000
Hemp	71,000 ,, ...	,, £3,900,000
Flax	41,000 ,, ...	,, £3,500,000
Silk	1,650 ,, ...	,, £1,900,000
Coir	4,370 ,, ...	,, £57,800
Other fibres	5,170 ,, ...	,, £116,900

Omitting cotton, silk, and wool, the others totalled 302,540 tons of £13,574,700 value. The manufacture of such quantities of fibre represented work for a large number of persons.

Dealing first with flax, the lecturer touched on its history, its botanical entity, its agriculture, and the principal sources of supply. Russia, he said, produced one-third of the total supply and dominated the market: a continuance of its development and methods would jeopardise all other producers and place the linen trade in an unenviable position. Reference was made to the preparatory processes through which the fibre passed and to the pedigree seed work done by the Linen Industry Research Association. This work had given a 30% increase in output of fibre and still further increases were confidently expected. Pulling, by hand or mechanically, retting, spinning, and drying were all briefly described. reference being made to the necessity for some good artificial drying process and to the number of handlings through which the fibre passed before it was ready for spinning. The lecturer claimed that the many good qualities possessed by flax should be more widely known and urged that they be better advertised. "Linen is used from the cradle to the grave" said Mr. Wigglesworth and claimed that though dearer than cotton it lasted longer and was cheaper in the long run. In a similiar manner, the lecturer dealt with the production, growth, and properties of hemp, Indian hemps, manila hemp, New Zealand hemp, sisal or agave, Mauritius hemp, maguey, jute, ramie, coir, and many minor fibres such as China hemp and jute, caroa fibre, pita, genistra, and brotex. Notable points made in connection with these fibres were that the real hemp plant is *Cannabis sativa* and most of our sports nets are made from this fibre; manila hemp is very strong and tenacious and floats in water, ropes for marine use should be pure manila. The production of New Zealand hemp (*Phormium tenax*), Mr. Wigglesworth pointed out, was hampered by high labour costs and freights and some efficient stripping machine was needed. The large development of the use of sisal for "binder" twine was noted, for which its immunity from insect attaches specially fitted it. Regarding jute, it was to be noted, said the lecturer, that the annual output from India was about 2,000,000 tons; it was water-retted and sun-dried; it was weaker than flax or hemp and employed mainly for articles used only once such as bags, sacks, bale wrappings, etc. Ramie had been rather a disappointment; millions of pounds had been spent on it but it had hardly come up to expectations.

Mr. John Howard said he was pleased to move a vote of thanks to the lecturer, but before doing so, he would like to congratulate the audience on having had the opportunity of listening to such a very good lecture. It was also remarkable to have put before them not only information as to the relative merits of different fibres, but a film also of their production. He was amazed to find how much work there was before one arrived at the fibre. Some years ago he had been very astounded to find how little fibre there was in the straw. He thought the development in future should be towards getting that essential fibre much more cheaply from the straw.

Mr. Meredith, seconding the vote of thanks, said he would like to say how very entertained he had been. For the first time he had seen some of the earlier processes on the screen. He thought that this method of teaching by the film, though in its infancy, was of great value. Particularly was he pleased to see the slow motion action of the looms.

Mr. Wigglesworth, responding, said it might now be realised why flax was expensive. The only way to cheapen it would be by increasing the fibre content, which seed selection could do, and by introducing mechanised methods.

Irish Section

Meeting at the Municipal College of Technology, Belfast, on Thursday, 6th November 1930; Mr. W. H. Webb in the chair.

IMPROVEMENTS IN THE QUALITY OF RAYON GOODS

Lecturing under the auspices of the Irish Section of the Textile Institute at the Municipal College of Technology, Belfast, last evening, Mr. A. J. Hall, of Manchester, a well-known investigator of the properties of rayon, or artificial silk, said that the three most important types of rayon were cuprammonium, viscose, and cellulose acetate, and their utilisation in woven and knitted textile materials ultimately depended upon their physical and chemical properties. All the properties required in manufacturing and processing of fabrics containing rayon could be related to the fine structure of the rayon.

The lecturer discussed the importance of modern views on the fine structure as revealed by X-ray methods and his own investigations in relation to the production of the filaments and the dyeing and finishing of fabric containing rayon. The view was now held that the rayon filament was built up of micellæ or structural units and it would appear that the utilisation of rayon was largely dependent upon whether the structural units in each thread were ranged parallel to the fibre axis or at random. Stretching of the rayon during manufacture or subsequent processes tended to the parallel arrangement whilst swelling treatments not involving stretching caused random arrangement. Thus, stretching of rayon in manufacture and finishing caused greater lustre, decreased resistance to creasing, and a reduced affinity for dyestuffs. Many lustre and colour faults were due to local or irregular stretching.

In the mercisation of cotton goods containing rayon, it was desirable that the rayon should withstand the process and not be adversely affected by the alkali. Satisfactory methods have now been devised to overcome these difficulties, and cotton materials containing rayon could now be well mercerised so that the rayon retained all its original good qualities. Appreciation of this progress should result in greater use of rayon in fabrics in which highly lustrous or mercerised cotton was required. The discovery of the connection between fine structure and the dyeing properties of viscose rayon had also enabled manufacturers to produce a higher grade product offering fewer difficulties in dyeing and finishing. As a result, the quality of goods produced was now very much higher than formerly. Further lines of research were suggested by recent advances and it was anticipated that several fundamental improvements would yet be affected in the manufacture and production of coloured rayon goods.

Scottish Section

Meeting at Paisley, Thursday, 25th September 1930.

A meeting of the Scottish Section was held on 25th September, when there was a good attendance of members from different parts of the country. Most of the party assembled in Glasgow and travelled by private saloon bus, arriving about 10.30 a.m. at the Gleniffer Soap Works, Paisley, where they were received by Mr. T. C. Storrie, Managing Director of the firm.

Mr. Storrie gave an interesting account of the preparation of different soaps and scouring agents, and explained the various uses to which they were put in the textile and other trades. A comprehensive display of the firms' products had been arranged, and members were given an opportunity of inspecting these during the course of Mr. Storrie's address. Thereafter, the members were conducted in parties throughout the works, and viewed the different processes employed in the production of bar, soft, and flake soaps, etc.

On the invitation of Mr. T. C. Storrie and Mr. James Ross (Seedhill Finishing Co. Ltd.) the members afterwards assembled for lunch at the Paisley Picture Theatre Restaurant, where they were joined by representatives from Messrs. Seedhill Finishing Co. Ltd.

Mr. J. Macpherson Brown (Galashiels) presided, and, on behalf of the Committee, extended a welcome to those members attending a meeting of the Section for the first time. He expressed satisfaction at the excellent attendance, and thanked the members present for thus encouraging and supporting the Committee in their efforts to arrange interesting and useful meetings. He also made an appeal for increased interest in the work of the Institute and for the necessity of bringing it before the notice of those who had not hitherto taken the advantage of membership. He believed it provided excellent opportunities for mutual consideration and discussion of problems common to all.

Presentation to Hon. Secretary.—During the proceedings, the Hon. Secretary (Mr. A. W. Blair) was presented with a handsome silver salver, suitably inscribed, to mark the occasion of his marriage. Mr. J. M. Brown, in making the presentation, asked Mr. Blair to accept, at the same time, their thanks for his work in the past, and sincere good wishes for his future happiness. Mr. Blair replied, thanking the members of the Section for this recognition of his efforts on behalf of the Institute, and commented upon the successful nature of that particular meeting and the encouragement received by such enthusiastic support.

Mr. James Ross, on behalf of Messrs. Seedhill Finishing Co. Ltd., said it was a pleasure to see such enthusiastic members of the Institute, representing so many different branches of the textile trade, and he hoped that by the end of the day's proceedings, they would all feel that the time had been well spent and that some tangible benefit would have been derived to their mutual advantage. He took the opportunity of welcoming the members to the works of the Seedhill Finishing Co., which would be visited in the afternoon, and hoped that the members would find the visit interesting and instructive.

The company then proceeded to the Seedhill Works, and spent the afternoon inspecting the different processes employed in the dyeing and finishing of the wide range of materials undertaken by the firm. Opportunity was also taken of viewing the Laboratory, Electrical Power Station, up-to-date Boiler-house, and Steam Accumulator Plant, in which the visitors took a keen interest.

Tea was afterwards provided by the Company in the works' canteen, when Mr. J. M. Brown, on behalf of the visitors, expressed sincere thanks to Mr. Storrie and Mr. Ross for their kindness and generosity in entertaining the members so handsomely during the day, and for the excellent arrangements made for their reception. He was sure that they all appreciated what these gentlemen had done to make the Paisley visit a memorable occasion. He also thanked those representatives of the two firms for the courtesy and consideration shown to the members during the tour of the works.

Midlands Section

First Meeting of the Section at the University College, Nottingham, on Wednesday, 22nd October 1930; Mr. T. Morley presided

SOME REACTIONS OF FOREIGN COMPETITION ON BRITISH TRADE

Mr. Morley, introducing the lecturer, Mr. A. N. Shimmin, Senior lecturer in Economics at Leeds University, said that this was the first meeting arranged by the newly-formed Midlands Section Committee. He trusted it would be the forerunner of many successful and useful events. He felt sure they were to have a very interesting paper that evening and he would at once call on the lecturer.

In his address on this subject Mr. A. N. Shimmin emphasised the mortgage which the war had placed on our productive system. In 1920–1921 the collapse of currency and credit added to the confusion of trade in both home and foreign markets. Although the outcome of the war was expected to be a larger measure of international co-operation, the post-war years had revealed a decided tendency in the direction of economic nationalism. The search for self-sufficiency or the deliberate protection of home manufacture was raising an increasing number of barriers between nations, and checking the flow of international trade. By quotations from the findings of the Balfour Committee and other official documents Mr. Shimmin explained the incidence on our trade of diminished consumption, the growth of manufacturing industry abroad, and the increase of foreign competition in markets in which British goods had been supreme in pre-war days. The rapid growth of competition from Japan and Italy in the Indian market was a pointed example of the redistribution of international trade. We had been warned repeatedly by official committees of inquiry that "the widespread growth of local manufacture has come to stay" and "the future of British commerce will depend in no small degree on the capacity of British manufacturers and traders to understand and react to these changing conditions." This process of reaction involved a study of complicated questions in the spheres of currency, costing, marketing, and technological research. The situation, Mr. Shimmin suggested, seemed to call for an economic council in each industry to survey production "from fibre to fabric," for it was clear that the more serious reactions of foreign competition could not be countered by the unorganised efforts of individual firms.

Mr. J. Chamberlain said he had been very pleased to hear Mr. Shimmin's paper and felt that everyone present had been given "something to think about." He would be glad to know the lecturer's views as to what had been the effect of debasing the Indian silver coinage, and on the spread of the "hire purchase" system. He could not avoid the conclusion that we should have to be satisfied with a lower standard of living.

Mr. A. L. Wykes said that he, also, had appreciated the clear exposition the lecturer had given of a difficult subject. He felt that what was needed was increased efficiency, more and more technical training and knowledge, and more extensive research. We should aim at offsetting any advantages our competitors might possess such as labour conditions, wages, etc., by improvements in organisation and efficiency in technique and management.

Mr. Shimmin, replying to the one or two points raised, said that undoubtedly the debasing of the Indian silver coinage had contributed to the present unsatisfactory condition of industry and that the "hire purchase" system created an artificial position which must have an effect on world credits. He agreed that we needed increased efficiency and again urged the need for united action in securing the information upon which such efficiency must be based.

Mr. J. Barr proposed a hearty vote of thanks to the lecturer which was accorded with enthusiasm.

Visit to Messrs. J. B. Lewis & Sons Ltd., Haydn Road Works, Nottingham

On Thursday, 13th November, the first of a series of visits to Midland Textile Mills was made by over 20 members of the Midlands Section of the Textile Institute, when the party was shown the extensive Haydn Road Works of Messrs. J. B. Lewis & Sons Ltd.

These premises have been planned for the mass production of knitted underwear, bathing costumes, full-fashioned hose, and other knitted goods. Whilst of a strictly utilitarian type, the buildings have been designed to facilitate every phase of economical working compatible with consideration of the employees. The disposition and arrangements of the departments are such as to secure an uninterrupted flow from yarn to finished article and all details such as grouping of machines, lighting, heating, and ventilating have been carefully thought out The welfare arrangements are complete, consisting of well-equipped canteens, rest-rooms, library, sports grounds, and swimming bath—the latter being of a distinctly luxurious type, the present of a former director of the firm.

After tea, kindly provided by the firm, Mr. Thos. Morley, Chairman of the Section, proposed a vote of thanks to the firm for the excellent way in which the programme had been carried out and offered his congratulations in respect of their modern methods of manufacture.

The Hon. Secretary supported the proposition and added that he trusted all members would give freely of their services as the success of the Midlands Section depended upon collective interest and the action of the individuals.

Mr. Adams and Mr. S. E. Ward, Directors of Messrs. J. B. Lewis, responded and Mr. Ward added that in building up such an organisation many facts were only ascertained by working under factory conditions. They believed that success could only be achieved by the collective efforts of employers and employees and that cheerful environment, proper incentive, and good management were necessary to preserve it.

NOTES AND NOTICES

Institute Annual Competitions

A satisfactory response has been secured in regard to the Institute's offer of prizes for the current year's competitions in relation to design and structure of woven fabrics and the production of fancy yarns. The competitions are open to advanced students at the various technical colleges and schools. Whilst it is possible to state that the exhibits generally reveal distinct improvement in the matter of commercial values, yet there is still room for wider geographical distribution of competitors. Amendment of the terms and conditions of the competitions, from time to time, has undoubtedly influenced wider representation of technical institutions, yet many such establishments continue to remain unrepresented. The distribution of the prizes for 1930 is fixed to take place at the Institute on the afternoon of Saturday 6th December, and Mr. John Emsley, J.P., of Bradford, Past-President of the Institute, has kindly accepted the invitation of the Competitions Committee to attend and present the prizes. At 6.30 p.m. on the same day, the members of the British Association of Managers of Textile Works will attend for the purpose of inspection of the exhibits produced by the competitors. On this occasion, it is hoped that the proceedings may result in useful discussion in reference to both exhibits and competitions. The Competitions Committee have at all times been not merely willing but anxious to give their consideration to suggestions from any direction which might lead to the betterment of the scheme of competition from the standpoint of usefulness to all the interests affected.

Coming-of-Age Celebrations

Although definite arrangements are not yet far advanced in reference to the forthcoming celebration of the Coming-of-Age of the Institute, yet a good deal of consideration has already been given by one or two committees to the framing of proposals in regard to the event. The celebration proceedings are to take place at Manchester on selected dates during the three weeks commencing 20th April 1931—two clear days, preferably Wednesday and Thursday, to be occupied. The Publications Committee has made suggestions regarding the Mather Lecture and a public lecture to be delivered in the course of the proceedings, whilst an important contribution is proposed in the form of publication of a review of progress in textile technology over the period of the past twenty-one years. It is hoped that all Members of the Institute will take an early interest in the event and any suggestions communicated would receive earnest consideration.

Federation of Textile Societies

The next Annual Meeting and Conference of delegates representing textile societies and kindred organisations in membership of the Federation has been fixed to take place at Burnley and Nelson on Saturday, 2nd May 1931. The invitation to visit the district indicated is from the Nelson Textile Society, the Burnley and District Managers' Association, and the Burnley Textile Society. Subject to minor modifications to meet local convenience, it is proposed to pay a visit of inspection to the Burnley Technical College and afterwards proceed to Nelson for inspection of the Technical School there, the proceedings of the annual meeting and the reading of papers to take place in the latter town. At a meeting of the Committee of Management of the Federation, held at the Textile Institute, Manchester, on Saturday 15th November, Mr. Norman Collinson, Batley, Chairman of the Federation, presiding, Mr. E. Holden, of the Burnley Society, attended to discuss arrangements for the annual fixture. It was reported to the meeting that there are now 36 societies in Federation membership as against 34 at the same time last year.

Death of a Distinguished Machinist

Of world-wide repute over a great many years for his leading association with the development of machinery for the winding of thread, Mr. Joseph R. Leeson, Chairman of the Universal Winding Company, of Boston, U.S.A., died on the 8th November, in London. Born in England in 1844, he lived at Leamington for some years, after which he proceeded to America where he became interested in the linen thread industry. Ultimately, he organised the Universal Winding Company of which he became President and owner of a controlling interest. In 1925, despite his great age, Mr. Leeson associated himself with the English executive of the company's organisation, directing the distribution of the Leesona machines in Europe and the East and leaving the newly-elected President in charge in the United States. The deceased had been for a number of years President of the Boston Merchants' Association and was the holder of many distinctions. Mr. Leeson was an individual of exceptional interest owing largely to his unassuming disposition. A few years ago, at the time of one of his occasional visits to this country, he called at the Textile Institute. Asked to address a meeting, or to give a lecture before Institute members, he immediately proceeded to inscribe a cheque in favour of the Institute's Foundation Fund and handed it over with the observation that he hoped the alternative might be equally useful.

The Midlands Section

A Midlands Section of the Textile Institute is now in active operation and a number of lectures as well as works' visits have been arranged. The formation of a Midlands Section should not only be advantageous from a regional point of view but should bring the Knitted Goods Industry in closer touch with the work of the Institute. The membership at present is approximately 80, but it is hoped to augment this by the obtaining of new members. Meetings will be held in all

the chief towns in the area where textile trades are carried on. By these means Educational Authorities and Manufacturers will come into close contact with each other and a closer relationship established between education and industry. More publicity will be given to the work of the various textile Research Associations and the value of the Institute's examinations for Associateships and Fellowships will be more generally recognised.

The Section Committee has been formed and hopes to be able to arrange lectures, visits, and social functions suitable for its own particular needs.

It is urged that all those Midlands Spinners, Manufacturers, Dyers, and Finishers who have a common interest in textiles will support the Midlands Section and assist in its development, thereby linking up their own interests with those of other sections of the great textile industry of Great Britain, which can only be maintained as an entirety by active co-operation of the many and varied textile trades.

Textile Institute Diplomas

Elections to Fellowship and Associateship have been completed as follows since the appearance of the previous list (September issue of this *Journal*).

FELLOWSHIP

RICHARDSON, Ralph Pilsbury (Bombay, India).

ASSOCIATESHIP

KOHNER, Rudolph Oscar (Podersam, Bohemia).

Institute Membership

At the October meeting of the Council, the following were elected to Membership of the Institute—F. Aldred, 16 Glenburn Street, Great Lever, Bolton (Beaming Overlooker); M. Chukri, 80 Chorley Old Road, Bolton (Textile Student); E. Cotterill, "Cyprus," Coggeshall Road, Braintree, Essex (Textile Technologist); E. P. Craven, 14 Hilton Road, Lidgett Green, Bradford, Yorks. (Textile Salesman); R. Crompton, 25 High View Street, Bolton (Power Loom Overlooker); H. Duxbury, Rydal Mount, Andrew Lane, Bolton (Power Loom Overlooker); F. Edmondson, Ribble House, Bank Hall Lane, Hale, Cheshire (Engineer, English Sewing Cotton Co. Ltd.) W. Emsley, 18 Salisbury Avenue, Armley, Leeds (Blending Assistant and Chemist); L. Feitz, 10 Grantham Road, Bradford (Textile Student); T. F. Foulkes, 29 Pensarn Avenue, Kingswood Estate, Fallowfield, Manchester (Textile Testing Assistant); F. Hern, "Hamerton," 55 Melton Avenue, Leicester (Hosiery Manager); G. McCann, 83 Beverley Road, Bolton, Lancs. (Cotton Spinning, Head Carder); W. D. Kennedy, 223 Whitehaugh Avenue, Paisley (Dyeing Foreman); A. A. Macdonald, Invercoe, Edge Lane, Chorlton-cum-Hardy, Manchester; A. W. Martin, "Rose-Dene," Parkcroft Road, West Bridgford, Notts. (Yarn Salesman); M. G. Phadke, 9 Enfield Avenue, Levenshulme, Manchester (Textile Testing Assistant); A. de Monchy, Lyndene, Wigan Road, Bolton (Textile Student); K. Nicholls, "Sledmere," Pearson Lane, Bradford; T. M. Pearson, 66a Radcliffe Road, Bolton (Apprentice); J. Pickvance, 158 Waterloo Street, Bolton (Side Piecer); J. Pilkington, 19 Clough Street, Bolton (Side Piecer); W. P. Powell, "The Croft," Leicester Road, Hinckley (Head, Hinckley Technical Institute); T. Roberts, 18 Armitage Buildings, Woodkirk, Dewsbury (Head of Textile Department, Technical Institute, Morley); W. E. Seddon, 335 Green Lane, Bolton (Trainee, Lancs. Cotton Corporation); N. L. R. Sheret, Braemar, Irlam Road, Flixton, Manchester (Textile Economist); S. Shorrock, 233 Greenmount Lane, Bolton (Draughtsman); S. A. Simpson, 58 King Edward Road, Loughborough (Textile Tester); A. Styan, 29 Heaton Avenue, Bolton (Side Piecer); Colonel G. Tanner, Fernhill, Greenfield, near Oldham (Manufacturer); W. Walker, 252 Deane Church Lane, Bolton (Salesman's Costing Clerk); T. Ward, 77 Wellington Road, Turton, near Bolton (Stripper and grinder); R. N. Winkley, Lyndene, Doe Hey Road, Great Lever, Bolton (Mill Manager, Cotton Spinning); S. Wood, 70 Birks Brow, Waterhead, Oldham (Under Carder).

REVIEWS

The Microbiology of Starch and Sugars. By A. C. Thaysen and L. D. Galloway. Humphrey Milford, Oxford University Press (pp.viii+336, 25s.).

This volume is issued as a companion to Thaysen and Bunker's book, "The Microbiology of Cellulose, Hemicelluloses, Pectins, and Gums," published in 1927, and, in their preface, the authors state that the two volumes together represent an attempt to review the microbiology of the carbohydrates. To summarise the material from some three thousand original sources has naturally meant drastic compression and, in many cases, a minimum of critical discussion. On the whole, however, the present volume may fairly be said to have materialised the authors' aims, in providing a useful summary of existing knowledge and in drawing attention to numerous fields still awaiting exploration.

The first part of the book has three chapters dealing with the biochemistry of the more complex carbohydrates, starch, glycogen, inulin and the tetra-, tri-, and disaccharides, followed by one chapter on the hydrolysis of glucosides by the action of micro-organisms, the latter including a somewhat sketchy account of the production of natural indigo. The next nine chapters, forming the largest section of the book, are concerned with the fermentation of monoses, and discuss an enormous mass of purely biochemical work. It is unfortunate that the explanation, on pp. 87-89, of the method of constructing a balance sheet to represent the action of a particular organism on glucose should be marred by complete confusion regarding signs. Part three is a short section dealing with the synthetic activities of micro-organisms and with the mucus fermentations. Part four reviews the microbiology of commercial starch products, cereals, milling products and bread, and part five deals similarly with sugar manufacture. This collection of information from a number of different industries concerned with the handling of carbohydrate material should prove very useful, in that a line of attack adopted in combating the destructive activities of micro-organisms in one industrial product may often prove suggestive to workers in another field. A curious lapse occurs on p. 243, in the discussion of the influence of reaction on the ripening of dough. The terms "hydrogen ion concentration" and "*p*H" are not always interchangeable and the statement that "the hydrogen ion concentration of a dough is unimportant provided it . . . does not fall below the *p*H value of 4·8" means exactly the reverse of what the authors intended.

The ubiquitous *Penicillium glaucum* once again occupies a prominent place amongst the fungi mentioned, although it is difficult to see what value, either theoretical or practical, can be attached to researches on such an indeterminate species.

The very numerous references to original papers are given at the ends of the various chapters, but an Index of Authors and an adequate Subject Index facilitate easy reference. G.S.

Les Applications des Rayons-X. By J. J. Trillat, D.ès.Sc. Les Presses Universitaires de France (298 pp., 108 figs., 85 francs).

A thoroughly readable and up-to-date book, this volume covers the theory and technique of X-ray examination and its applications to physics, chemistry, and metallurgy. The amount of ground covered is very considerable and, although some of the topics are dealt with only briefly, the author has succeeded in producing a book which cannot fail to be both interesting to the novice and stimulating to the research worker.

In the section devoted to metals, the author deals with atomic structure, allotropy, grain size, and internal strains. He then proceeds to deal with other inorganic materials—cements, ceramics, pigments, asbestos, photographic emulsions, and pearls. In the field of pure organic chemistry, the subjects of long carbon chains, lubricating and drying oils are considered in some detail.

The general section is, however, possibly the most interesting to readers of this *Journal*. This part of the book deals with colloids generally, and with cellulose (including rayon), rubber, gelatin, and other proteins. The book concludes with a section on mesomorphic phases ("liquid crystals"), quantitative and qualitative analysis by X-rays, and the technique of radiography.

The section on cellulose is quite good; it gives a very fair account of the present position in this field. There are a few misprints, but these are mostly obvious and should do no harm, e.g. hydracellulose in Pl. xii and on p. 193,

trinitrocellulose $C_6H_{10}O_5(NO_3)_3$ for cellulose trinitrate, and fig. 89 for fig. 87 on p. 191.

A feature of the book is its excellent bibliography; the printing is good and the illustrations, the paper and binding are fair. H.

Silk and the Silk Industry. By Joseph Schober, translated by R. Cuthill, M.Sc., Ph.D. Published by Constable & Co. Ltd., London, 1930. (Pp. xi—375, illus., price 21s.)

The author has not been content merely to compress into one book the whole subject of silk in all its aspects, which really occupies a very extensive literature; he has gone further and has devoted much of his limited space to external matter, such as the history and manufacture of several varieties of rayon. There is no doubt that had the fifty-odd pages given up to this extraneous matter been devoted to the subject indicated by the title, much of the sketchiness of other chapters could have been avoided. In his preface the author points out that he has been careful to avoid technical expressions as far as possible.

The first chapter deals generally with the cocoon and its history. It is of interest to note that though silk was in common use in India and Persia, it was, according to Schober, unknown in Babylon, Egypt, and Palestine. In a section on the industry in England, added by the translator, it is stated that silk was the subject of an Act of Parliament in 1363, which indicates that it had been in use long before. An interesting illustration is one showing the silkworm's development every day of its month of activity.

Very courageously, the author gives what he calls a close approximation of the production of silk in China, but as he seems to be under the impression that the "normal dress of men, as well as of women, is largely composed of silk," which is erroneous, it is probable that his estimate is not correct. In the yarn section, which is perhaps the best in the book, the statistics have been brought well up-to-date, and the part describing usages of the trade cannot fail to be useful, though the unconventional spelling of Japanese words in the glossary makes it difficult to find certain terms; for instance, the Choshin grade of raw silk is placed under letter D.

Passing over the rayon chapter, the section given over to silk weaving is very full and informative, some prominence being given to what Cobden said in 1860: "Let the silk trade perish and go to the countries to which it properly belongs." The statistical part of this division of the book should be carefully studied.

One could have wished that something more than ten pages had been given to the chapter on ribbons, and more than 26 pages to the enormously important knitting industry. If Chapter III had been omitted, these two notable branches of the silk business might have received treatment commensurate with their importance.

The final chapter deals with durability, strength, and serviceability, and the methods of determining these. In one place the author states: "For the best quality of ladies' underwear, linen is always used instead of cotton." One cannot help wondering how such a phrase can appear, even with modifications, in 1930. The methods of testing advocated, include most of the well-known processes. Special note should be taken of the fine bibliography and of a very useful vocabulary of silk terms in English, French, German, Italian, and Hungarian. There are many illustrations which add to the interest of the book; among the different forms of weaving machinery is a "Chinese" loom being worked by a Japanese woman. Speaking generally, the book has value for the public rather than for the technician, but at the same time the latter will not fail to find much valuable information. P.

Manufacture of Knitted Footwear. By John Chamberlain, F.T.I.

This is Volume III of a series of text-books written for students of the knitting branch of the textile industries. It will still further reduce the demand for a work now out of print, of which the writer of this volume was joint author. The author states that this book has been written to show the development of knitted footwear manufacture from the year 1589 to the present time. It will not fail to convince the reader of the several sections into which the manufacture of knitted footwear is of necessity divided. Chapter I deals with the history of its development, and comprises a collection of data concisely arranged to be extremely interesting to the student, and invaluable to those in the industry of an inventive turn of

mind. Chapter II opens with a classification of the innumerable varieties of knitted footwear, (*a*) according to type and size, (*b*) yarn and gauge, (*c*) process of manufacture, (*d*) according to stitch, design, or colour, covering some nine pages and followed by modern principles of the manufacture of "Full-fashioned Selvedged," "Full-fashioned Seamless," "Fashioned," "Fabric" or "Cut," and "Seamless" knitted footwear. This chapter includes the divisions of these types, giving count of yarn, gauge of machine, and subsidiary machines required for each division. Demand will compel increasing attention to composition of material, and to variation from sizes enumerated under classification (*a*). Chapter III allocates the making of full-fashioned knitted footwear to seven frames or machines. Five of the frames are of the Cotton's type, to which 34 pages are allotted, and freely illustrated with the modern type of frame and attachments. Volume I is referred to for other attachments on this type of frame, and also to flat-machine cam systems and jacquard mechanisms. Chapter IV is on modern seamless hose machines and occupies 43 pages with 20 illustrations, of which 15 are detailed drawings. This chapter describes the "Maxim" plain and fancy machines, "Standard-Trump," "K" model with inturned welt mechanism, and the "W" model or spring needle hose machine. Reference is also made to Volume I for other mechanism connected with the manufacture of seamless hose. Chapter V first deals with rib-tops which are afterwards transferred to plain machines, and is covered in five pages with illustrations. Four pages illustrate and allude to methods used to a limited extent in the manufacture of seamless rib footwear, and in the remaining 26 pages is given a description of the most modern super-imposed cylinder machines of the stationary and revolving cylinder types, including the "XL," "XL-sior," "Autoswift," and "Komet," with illustrations of looping elements, transferring mechanism, cam systems, chains, and set-outs. In Chapter VI the manufacture of fancy half-hose, socks, tops for ¾-hose, golf-hose and tennis socks, and ladies' sports hose, etc., is covered under two headings—(*a*) Fancy Stitches, and (*b*) Yarn Manipulation. Section (*a*) occupies some 18 pages in describing the effect produced from certain stitches, and the movements of the elements concerned. Section (*b*) of 24 pages describes the several methods of controlling the looping elements and yarn feeders, to secure the necessary manipulation of the yarn. The remaining six pages give a synopsis of methods of designing, pattern limitation and variation. Chapter VII refers to the subsidiary processes subsequent to knitting, as linking, seaming, welting, and embroidering, each of which are dealt with respectively as "linking," guage, stitch, mechanism, "seaming," point, selvedge or cup, and overedge "welting," methods, stitch formation and mechanism. Ten detailed illustrations are distributed over the 25 pages concerned. Chapter VII is composed of 31 pages dealing in a general manner with the complex subjects of dyeing, finishing, and factory organisation. To quote the words of the author, "dyeing and finishing problems are encountered such as are unknown in other branches of the textile industry." The work is essentially a text-book, and will be found to be a serviceable continuation of Volumes I and II by the same author. H.

Calculations and Costings for Knitted Fabrics. By W. Davies, M.A. Published by Sir Isaac Pitman & Sons Ltd. (226 pp., price 10/6).

The author in a short preface comments upon the inadequate amount of literature on the subject he deals with. As far as calculations are concerned the work is covered in a fairly comprehensive manner by Ernest Tompkins in his "Science of Knitting" which was first published in 1914. The book has recently been revised and the same author has also published a smaller and simpler treatise on Knitting Calculations. There is also John Chamberlain's "Knitting Mathematics and Mechanisms" published in 1923. This book has a chapter on costing of knitted garments.

The book under review is subdivided into 12 chapters and there is an appendix containing worked answers to calculation questions set in examinations in hosiery manufacture, most of the questions answered being taken from papers set by the East Midlands Educational Union. The first chapter is concerned with the texture of plain knitted fabric. Similar textures are defined as those which have the same number of loops per square inch. Thus, to quote from an example, a fabric with 10 wales and 28 courses per inch is considered as of similar texture to one with 20 wales and 14 courses per inch. This is not in accordance with other widely-accepted meanings of the term.

Chapter II on the methods of gauging knitting machinery will, it is to be feared, more confuse the reader than help him. Some useful data is given in Chapter III which deals primarily with the relation between yarn count and machine gauge. Fashioning calculations which seem logically to belong to Chapter VIII have found their way into this chapter. An objection must be raised to these and to several of those in the 8th chapter by reason of the fact that no allowance has been made for fabrics contracting in width after they leave the knitting machine. On a machine having 10 needles per inch it is assumed that the fabric is narrowed three inches by reducing its width 30 wales (example 7, page 33). This implies that the fabric width is equal to the needle width. In another part of the book the author states that fabric from circular machines contracts 35%, and from flat machines 12%, after it leaves the needles. In addition to the subjects mentioned there are chapters dealing with calculations on the following—fabric weights, production, yarn counts, warp fabric, conditioning, pulleys and gearing. One chapter is devoted to costing of sewing and seaming threads, and one to costing of knitted garments.

The arrangement of the chapters is open to some criticism. Chapter VI, which gives the various yarn numbering systems used in the hosiery trade, would preferably have preceded Chapter III in which the sytsems are used without having previously been made known to the reader.

Instead of adopting the cotton-denier conversion figure 5314·9 recommended by the Textile Institute, the author prefers to retain the old constant 5282·5 and justifies his action on the grounds that the old number is firmly fixed in the hosiery trade and in the one used by the Customs officials* in estimating percentage of silk and artificial silk in mixed fabrics. Excluding those in the appendix, the book contains 189 typical examples of textile calculations, each one fully answered. Its value to the student is in the number of exercises it provides in simple applied mathematics J.B.L.

Les Phénomènes de Teinture. By Dr. Justin Mueller. L'Edition Textile Paris. (371 pp., price 110 francs.)

According to the sub-title this book claims to be a theoretical and practical manual of dyeing and printing. It is really a dissertation on the author's theory of dyeing.

It is divided into three main parts. The first part is a very comprehensive history of the theory of dyeing, the views of other workers being all sympathetically treated without (as is so often the case) undue prominence being given to German researches.

The second part deals with the facts of dyeing and printing iu the light of Dr. Muellers *turgescence* theory. It is a very clear exposition, and what faults there are lie in the theory itself.

The third part is devoted to the description of the experiments made by the author in the course of his work with discussion of the results obtained.

The book concludes with a comprehensive bibliography of researches on the phenomena of dyeing and printing and on the whole is a very interesting contribution to the literature on this subject. R.G.

Skinner's Cotton Trade Directory of the World, 1930-1931. Compiled and published by Thomas Skinner & Co., London. (1,351 pp., 30s. nett.)

This is the eighth issue of a Cotton Trade Directory now well known; so well-known perhaps as to be called just "Skinners." The announcement is made that in order to provide subscribers with up-to-date information as to the cotton trade, the proprietors have purchased *The Textile Weekly* wherein will be included from time to time information received too late for insertion into this directory. The Preface claims, and rightly as we think, that much has been done to improve this reference work. Suggestions being asked for it is thought opportune to point out that the inlet thumb guides might be redescribed or differentiation secured therein, with advantage. The main divisions of the book follow the logical broad divisions of the industry and its ancillary trades but these thumb guide titles are not clear. For example the heading "Spinners and Manufacturers" forms one such guide and this is actually correct in its indication, but it is not

*This would appear to be an erroneous conception, as a Notice issued by the Commissioners of Customs and Excise—Notice No. 132, January 1928 for "Declaration of Artificial Silk Content for drawback purposes, etc." expressly uses the conversion figure 5314. Ed.

clear that the guide labelled "Italy" only refers to spinners and manufacturers in Italy and does not include bleachers, dyers, and finishers in Italy. Indeed these important sections of the trade are camouflaged under two guides, "Yarns" and "Piece Goods," under which one normally expects to find agents and merchants of such goods. This feature of an otherwise excellent directory might well receive the attention of the publishers. T.

The Yorkshire Textile Directory, 46th Edition, 1930-1931. Published by John Worrall Ltd., Oldham. (262 pp., 16s. nett.)
This directory—"one of Worrall's"—contains no sort of guide from the publishers as to any new features, and makes no claims beyond those set out in an "order" slip distributed in advance. This slip claims "Solid Facts—No Padding—Complete Index—Brevity" and so far as such claims may be tested it is possible to say that they are justified. The "No Padding" explains the absence of "Preface" no doubt. But the Directory tells its own tale, on two counts at least, if not more. It has managed to keep advertisements off its right-hand pages; and it has managed to persuade some if not all of its advertisers that "lay-outs" which went well with the first edition are likely to look somewhat out of place in the 46th. Indeed very hearty congratulations can be extended on both these points. When will all advertisers realise that they lose more than they gain by mixing their matter up with the "reference" matter which constitutes the *raison d'être* of a directory. One small suggestion may be ventured: put a "Contents" list (with page numbers to facilitate quick reference) on page seven and commence the Index to towns and villages on page nine. T.

International Telephone Directory (Annuaire Telephonique International). Issued by the A.T.I. Co., Copenhagen. (900 pp., 24s. including insertion of name, etc.)
This Directory has more than doubled its size on second appearance. It is difficult to appraise its value since that can only be apparent to those who use it. The publishers claim on its behalf that it—

(*a*) Is a World Telephone Directory.
(*b*) Is published in four languages, English, French, German, and Spanish.
(*c*) Is daily before the most efficient and important business firms at home and abroad.
(*d*) Gives a quick and direct answer to the question—"What are the firms of importance in a certain line of business in any particular country?"
(*e*) Brings England into close touch with the Continent by direct telephonic connection.

The Directory is published annually and a firm can have its name, trade, address, telephone number, and telegraphic address inserted for 24s. and receive also a copy of the Directory. The representatives in this country are Messrs. Rassey Bros., 28 Basinghall Street, London E.C.2. T.

Year Book of the National Association of Cotton Manufacturers, 1930. Published by the Association, Boston, Mass., U.S.A.
The current issue contains all of the features which have made the work known as a very comprehensive compilation of data of interest to all manufacturers. At the same time, through rearrangement of statistics and other material the volume has been made slightly smaller and more compact. The conservation of space has been made with no sacrifice as to size of type and legibility and has made it easier to find the information desired. Among other things, the book presents the cotton manufacturer with a detailed picture of the particular parts of the cotton crop in which he is interested.

Statistics from the most recent census available include more sub-divisions by classes of fabrics and divide the production of cloth into groups of fabrics with yarn numbers averaging 40's and below and above 40's.

The present volume is believed to include practically all of the authentic information about the industry that manufacturers and other interested persons might want. Since the publication of the first Year Book in 1918 changes have constantly been made, new tables added in the statistical and technical sections, and revisions made to keep the data up-to-date. T.

GENERAL ITEM

Design and the Cotton Industry*

In June 1924, a Joint Standing Committee (Industry and Education) of the British Cotton Industry Research Association was established as an outcome of a suggestion by the Board of Education that, the Association having powers under its constitution to make recommendations concerning the Education of persons engaged in the various branches of the cotton industry, such powers should be exercised. In the course of the discussions of the Joint Standing Committee which consists of representatives of Trade organisations and of local Education Authorities, the question of the training of designers for the industry arose. While some members had views on the question, the Committee as a whole felt that it required further information as to the attitude of Art Schools to industrial design, and as to the provision made by them for the training of textile designers.

This problem and those arising out of, and kindred to, it are by no means new. For more than 90 years they have exercised the minds of various Special, Select, and Departmental Committees and, in more recent years, of Industrial and Art Associations. Much of what was written in 1836 could be truthfully repeated in 1930. From that time to this, along with frequent declarations of the great importance of an improvement in the application of art to manufacturers, there are also admissions of the superiority of French designers, signs of mutual distrust between artists and industrialists, and complaints, on the part of industry, of the aloofness of the schools and of the lack of practical value in their work. It is, therefore vitally important that effective means shall be found to draw into the service of the industry men and women of trained artistic ability. This is being done by other industries, notably those in the Potteries, Birmingham, and Leicester, and the cotton industry cannot afford to remain indifferent.

The deliberations of the Joint Standing Committee were aided, in 1928, by the preparation of a report (contained in this Pamphlet) by two of His Majesty's Inspectors of Schools with a view to supplying the "further information," required by the Committee, referred to above. The scope of the report exceeded its terms of reference because it was realised that the "attitude of the Art Schools" and "the provision made by them" were so closely related to the attitude of the Industry to design, the designer and the schools that they could not be separated. Further, in view of the suggested superiority of Continental Schools it was thought desirable to include an account of the impressions gained from visits to ateliers and schools in Paris, Lyons, St. Gallen, and Cologne. The report was made under the following heads—Design in the Industry; Design in English Art Schools; and Design in Continental Art Schools. Its conclusions are then tabulated and cover the Fabric Printing Industry and the Weaving Industry. These conclusions and recommendations were considered by the Joint Standing Committee which presented, in the same Pamphlet, a memorandum expressing its views. No adequate picture can be drawn of this Pamphlet without almost complete quotation and it is not the object of this record to do more than draw attention to a document which merits the widest recognition.

One recommendation in the report described above, and a recommendation that was endorsed by the Joint Standing Committee must be recorded. The report suggests "that steps might be taken—to arrange in Manchester an annual exhibition of work done in schools not only in Manchester itself but also in the schools throughout Lancashire and Cheshire. A special effort should be made to secure the attendance of members of the trade and heads of studios so that they may have opportunities of seeing what is actually done in schools." This recommendation was made in respect of both woven and printed fabrics. Though but one part, and a relatively small part, of the functions of the Joint Standing Committee, the holding of an exhibition on the lines suggested above was considered of real importance and, in due course, came to actuality. An Exhibition of Designs for Printed and Woven Textile Fabrics by students of Schools of Art and Technology in the cotton area, was opened at the City Art Gallery, Mosley Street, Manchester, on Friday, 7th November 1930, by the Rt. Hon. the Earl of Derby. There was a very large attendance at the opening proceedings over which the Lord Mayor of Manchester (Councillor R. Noton Barclay) presided. The Lord

*Board of Education. Education Pamphlets, No. 75, 1929. H.M. Stationery Office. Price 6d. nett.

Mayor said that the aim of a school of art in relation to the industry was, as he understood it, not so much the production of the finished designer as to turn out students with a sound training in the value of form and colour, and also with imagination and freshness of mind, students who would develop into creators of attractive novelty in design. Novelty coupled with quality was what the world wanted to-day, and what the world markets would buy, even in bad times. They were anxious, therefore, to stimulate as much as possible by that Exhibition the work of the schools in relation to the industry.

Lord Derby in opening the Exhibition, said that in the old days, the cotton industry in Lancashire stood for itself. It neither required nor got any "puffs," but now they had come to a time when everything possible that they could do to advertise cotton goods had got to be done. Such Exhibitions as that, and the big Textile Exhibition, to be held in London in February, were necessary to bring the industry not only before foreigners, but even before our people at home. But the Exhibition, he continued, represented something more than the bringing together of art, education, and industry. Those in industry required to be quite satisfied that the quality and originality of the students' work was what it ought to be. In this the Exhibition was an attempt by the students to show the industry what they could do. It should serve to show the students and their teachers where they were making mistakes, and how these mistakes could be remedied. But it would also, he hoped, show the industrialists that the students had been well educated and it could bring nothing but good to the industry in the future.

Alderman Travis Clegg (Chairman of the Lancashire County Council Education Committee) in moving a vote of thanks to Lord Derby, said he hoped the Exhibition would attract those in the industry who looked with no friendly eye on the educationist, regarding him as one who added very largely to their overhead charges without bringing much apparent return. They would see there something that only scholastic training could produce. Such designs could only be produced through the development of technical skill by educational means. Despite the trade depression the attendance at technical and evening schools in the county area had increased from 29,000 to over 40,000.

The resolution, seconded by Mr. Herbert W. Lee, President of the Manchester Chamber of Commerce, was carried, as was a vote of thanks to the Manchester Art Gallery Committee and its Chairman, Alderman E. F. M. Sutton, proposed by Mr. Forrest Hewit, Chairman of the Joint Standing Committee (Industry and Education) of the British Cotton Industry Research Association, who said that he was glad of the opportunity which the vote of thanks furnished him of being able to mention the services of Mr. Edmondson and of Dr. Pickard. As Chairman of the Sub-Committee, whose work had been the conception and preparation of this Exhibition, Mr. Edmondson had performed an inestimable service to the Industry and to the Schools. It was also to be put on record that without the interest and co-operation of Dr. Pickard the Exhibition could hardly have taken place.

Alderman Sutton, responding, said the Art Gallery was naturally anxious to help the work of the art schools as of any other organisations which are developing training in industrial art and on those grounds they were glad to place rooms at the disposal of the Exhibition Committee. The examples of work submitted had been weeded out, largely because there was not room to show everything, but, in spite of this selection, he confessed the result to him was disappointing. There were a few good features in some of the schools, but as a whole the exhibits seemed to him somewhat lifeless, and monotonous, and unrepresentative of the public taste to-day. He contrasted with it the freshness and originality in designs and fabrics from abroad. If, however, the Committee by allowing the Exhibition to be held there, had helped to show that the schools of art were not producing sufficiently original designs, it would have assisted both the cotton industry and the schools of art.

The remarks made by Alderman Sutton, were widely reported and as some measurement of the Exhibition will undoubtedly be made not only by those who visit it, but by those who pass judgment upon it "from the armchair," the following is an attempt to orientate the Exhibition, as it is thought, accurately. The catalogue issued by the Joint Standing Committee records that examples of designs or fabrics are on view from some 30 Schools of Art and Technical Schools and Colleges; over 600 separate examples having been assembled. In a "Foreword" the catalogue says—

"The purpose of this Exhibition is at least two-fold. Immediately, it is intended to show everyone interested what is being done in the art schools and technical institutions of the cotton textile area to train designers whether for calico printing or for the production of woven patterns. Incidentally, it will let the schools see what others are doing, and further it will let industrialists, after seeing what is being done, help by advice and in other ways to bring the schools into fuller and closer relation with their needs.

But its deeper and more important purpose is to be another link in the chain of events initiated under the ægis of the British Cotton Industry Research Association, with the blessing of the Board of Education, to lesson the age-long lack of co-operation between British producers and British art schools.

That industrial art in this country should still be glad of any champion ready to break a lance on its behalf is one of the mysteries of the day, above all in the textile world, where the pleasing appearance of goods often has even more to do with securing a sale than their quality.

Our manufacturers and workpeople alike are proud of the reputation they enjoy for the skill which goes to make a piece of well-woven cloth; there should be—but how rarely is it displayed—no less cause for pride in the beauty of design or colour which first causes cloth to find favour in the eyes of the buyer.

Public taste in articles of everyday use is to-day higher than ever; the appetite for beauty grows by what it feeds on. And yet, in "Lancashire" (using that term in a generic and not merely a geographical sense), whose spindles and looms, whose bleaching, dyeing, and printing works are still the greatest industrial phenomenon the world has seen, it is rarely when men meet on their lawful occasions and talk about cotton trade affairs that intelligent discussion of design and colour is heard.

If this Exhibition can do something to establish a greater degree of art-consciousness in the community, a pride in artistic achievement not less than exists in regard to the technical excellence of our textile fabrics, it will not have been held in vain. Moreover, it will bring its own reward

Speaking generally, the exhibits are the normal output of the schools produced without regard for such an occasion as this Needless to say, they by no means represent the whole of the work done in the schools, where the training usually embraces also most branches of fine art as well as nearly every phase of industrial art. But there was everything to be said for holding an Exhibition specially associated with an industry whose requirements in the way of design are so manifold, and it was only fitting that such an Exhibition should be held in Manchester, whose name is familiar in the uttermost parts of the earth through its association with this country's paramount reputation for cotton goods."

This should emphasise what were the aims of those who organised the Exhibition and in extension of this record expressions of opinion* have been secured from representative sources and follow hereunder.

Mr. W. Turnbull, of Messrs. Turnbull & Stockdale, Manchester, said—The Exhibition of the students' work has interested me very much indeed. One has, of course, to resist the temptation to treat the exhibits too seriously by comparing them with the best professional work—it should be remembered that it *is* students' work. Nor do I think we should be too critical on purely technical points, although as a matter of fact there is little to grumble at in this connection. What, in general, the Exhibition *does* prove beyond any doubt is that there is no lack of talent in the Art Schools of the cotton area. True, there is too much evidence of a straining after effect, and too little evidence of a proper appreciation of colour combination, but on the other hand there is clear evidence of a spirit of adventure and experiment formerly lacking in the work of the Art Schools. One misses, and is thankful for it, that "museumy" look so characteristic of pre-war work. In many schools the students are obviously being "given their heads," and I am certain this is the right policy and should bear fruit later. On the whole, it would be untrue to say that the schools have made good their challenge to industry—what they *have* done is to prove that they are ready for a much closer co-operation with industry (both manufacturing and distributing) than has hitherto obtained.

Mr. J. W. Baron, of Messrs. Boardman & Baron, Great Harwood, said that the following features impressed him. The large proportion of the designs submitted were for printed fabrics as distinct from woven goods. A relatively small proportion of these exhibited delightful colouring. There was a lack of balance in displays from various schools; some schools were dominant, others almost insignificant. It was his general impression that art teaching in Lancashire from the elementary school upwards needs special attention if the county is to lead in the production of fashion-fabrics.

Mr. R. A. Dawson, Head of the Manchester School of Art, said the Exhibition shows that the schools are doing more in the training of designers than manufacturers were prepared to admit. It offers industrialists an opportunity of studying

*These are the opinions of their authors and do not necessarily represent those of the Textile Institute—EDITOR.

the educational side, and if sympathetic co-operation is to develop, misunderstanding must be cleared away. Judgment must take into account the age, time for study, and previous education of the student. If the manufacturer fails to find exactly his type of design ready to hand or only in limited quantity, that does not condemn the training. Many other examples could have been shown and can be seen at the schools. There existed two opposing criticisms of schools of art and the Exhibition has exploded both these. They were (1) that the schools did not train on the side of practical craftsmanship, (2) that the schools should develop ideas, originality, and creative suggestions to infuse new life into dead styles in a world of increasing competition. To meet these criticisms two types of provision have been made in Manchester (1) for the training of the designer-craftsman, (2) for the entended training of the professional creative designer. Industry requires both types. Dependence on the craftsman alone will bring downfall in design, and the introduction of the creative artist into industry above apprentice age with extended broad training and under suitable conditions is the means of renewed life. The work of the schools varies considerably in quality of design and artistic outlook, suggesting varied imperfections in training. In general, however, the art schools have made more advance than the technical schools. A school cannot reproduce the conditions of industry, but it can select ability and develop it to a high pitch of adaptability ready to be utilised in the sphere in which it is applied.

Professor A. F. Barker, Department of Textiles, Leeds University, said an Exhibition such as that at present being held in the Manchester City Art Gallery should fulfil two requirements if a large measure of success was to be attained. First, it should show evidence of design in its general arrangement and display; second, it should show evidence of inspiration and skill when examined in its details. The "general display" factor should have reference to the scheme for each school exhibit and also to the general scheme for all the exhibits. In neither of these respects does this Exhibition show evidence of endeavour, let alone of success. The Hyde School of Art exhibit comes nearest to what is desirable as an individual display, but as a whole the schools individually all show lack of appreciation of this essential This, perhaps, is not surprising, for even the Bradford Exhibit at Wembley was undoubtedly lacking in this respect, and more recent trade exhibitions have shown an utter lack of appreciation of this dominant factor. It may be urged against this criticism that there was no special preparation for this Exhibition, but the fact remains that an opportunity has been missed to give a lead in a direction in which we as a nation, along with our Overseas Dominions, are markedly lacking. On the second score—inspiration and skill in its details—the Exhibition is much more satisfactory. Most of the large schools show skilful work and, in some few cases, talent amounting to genius may be detected. Many of the schools, unfortunately, show a limited inspiration, and, as is often the case, technical excellence is too often linked with ineffective design, or design of a really promising type is linked with a lack of appreciation of the limits of the technical rendering. This must inevitably be so, so long as design is taught, even in our Universities, under limitations which preclude that "abandon" and "trial and error" on a large scale, more necessary here than in any branch of the industry. Perhaps the greatest service that this Exhibition could render to the industry would be to bring about a realisation that an artistic cultural outlook, associated with generous opportunity for experimental work, might work wonders in our textile designing. It can be done at the top in one way only. Make the Universities of Manchester and Leeds, in combination with their Art Schools, and suitably linked up with all the art schools in the textile districts, responsible for the spending of thousands of pounds on the lines which America has proved to be so successful, and in a generation designers will be evolved who will change the paper inefficiency or mechanical deadness of too much of the present-day design into living pulsating design which will truly represent the artistic aspirations of our people.

A representative of the Board of Education writes—The interest of the Board of Education in the training of textile designers is shown not only by the presence of four of their officers at the opening of this Exhibition, but also by their having arranged for the preparation by two of their Inspectors of the pamphlet on "Design and the Cotton Industry." The suggestion that steps might be taken by the industry to arrange in Manchester an exhibition of work done in the art and technical schools, not only in Manchester itself but throughout Lancashire and Cheshire, was first made in this pamphlet. Anything which promotes closer co-operation between education and industry is of great importance, especially at this time. The complete training of young men and women who are entering industry is not a matter for the school alone, or for industry alone. It is a task to be shared between the two. In this Exhibition we see the results of the work of the school alone. It is important to bear two things in mind if the designs submitted by the schools are to be judged fairly. In the first place there was no special preparation; the designs shown represent the ordinary current work of the schools. In the second place they are the work of immature persons (in some cases as

young as 15 or 16) working under school conditions. It would be unreasonable, therefore, to compare them with the designs of mature artists, working under trade conditions and possessing an adult's experience and outlook. On the other hand, it is not unreasonable that the schools should show industry what they are doing, and that representative industrialists familiar with the needs of the Cotton Industry should have an opportunity of forming an opinion as to the extent to which the schools are laying a sound foundation and giving the sort of training which will enable the students when they pass into the ateliers of the great firms or otherwise take their places in the industrial organisation, to be of the greatest possible service to the industry, and to enjoy the moral satisfaction of being conscious of rendering this service. In addition to this main purpose the Exhibition gives the schools an opportunity of comparing notes, while the individual school is enabled, perhaps for the first time, to see a large representative selection of its work in a public exhibition. On all these grounds it may be confidently anticipated that much good will follow from the Exhibition, on the success of which all those who have participated in its carrying out are to be heartily congratulated.

Major J. A. Barber-Lomax, of Messers. Arthur Bromiley & Co. Ltd., Bolton, writes—In considering the merits of the various exhibits in the large collection brought together as designs for textile fabrics, one must remember that such an Exhibition is necessarily divided into two Sections—the technical structure, weaves, and effects; and the artistic design. It is not to be expected that students during the progress of their education in the intricacies of structural design will produce examples which are very different from those produced by previous generations of students. Many of the examples which come under this heading are, therefore, commonplace, and show no striking departure from fabrics produced years ago. Just as the artist has to learn the fundamental rules of composition which, later, may be departed from or varied in the painting of pictures, so the technical student has to be proficient in a technical sense. There are also limitations as to the coloured yarns available in the various colleges, and restrictions to the use of such colours has given a "drab" appearance to this section of exhibits. In fact, the criticism of "dull uninteresting colour schemes" applies to most of the woven fabric exhibits. Turning to the designs for printed fabrics, I think here is shown a high level of excellence. Here there is no limitation of colour; the whole paint box is at the disposal of the artist. Many of the exhibits show considerable promise and are designed with proper regard to the use to which the fabric is to be put. Speaking generally, the designs from the various Schools of Art show a higher degree of excellence and appreciation of the modern tendencies of design and taste than the exhibits from the Technical Schools. This, perhaps, is not surprising and it can be said that the Exhibition will do good and enable students to see their colleagues' work in other towns. It is hoped that similar exhibitions will be held each year so that a friendly rivalry can spring up between schools, suitably fostered if necessary by the awarding of prizes, and to raise the general standard of the work exhibited.

Mr. J. H. Cronshaw, Head of the Heginbottam School of Art, Ashton-under-Lyne, said—Textile manufacturers, educationists, textile designers and students are under a debt of gratitude to the Joint Committee of the British Cotton Industry Research Association for organising this exellent Exhibition of Designs and Fabrics. The mode of display also makes it clear that the Education Authorities are doing all in their power to encourage the study of design and the technique of weaving. The manufacturer and customer (usually feminine) look for two qualities in a woven fabric—(*a*) good structure (utility and serviceability), (*b*) pleasing appearance (colour, pattern and texture). The woven fabrics shown are thoroughly British in their structure and certainly display evidence of sound practical and technical training on this side. When it comes to taste and judgment (colour and pattern) I find myself in agreement with Alderman Sutton—that the exhibits lack freshness, originality, modernity, and those qualities which a vigorous imagination allied with knowledge supplies. In Continental Exhibitions, schools and studios, I have found design a little more adventurous and colourful with a searching for new forms and brighter colour combination. An examination of the printed design section satisfied me that British printed-design students are not in any way behind Continental students. There are many examples of woven fabrics which are entirely satisfactory and would satisfy the taste of, say, 75% of the home market customers —those who demand reticence and safety. The other 25% would find them dull from want of contrast between figure and ground; from minuteness of the motive; from the small distance between the repeats; and often from a faint-hearted sickliness in colour. They are lacking in interest and novel excitement because the designer has relied upon old motives and upon naturalistic and botanical forms. There has been failure to realise that abstract, symbolic, and figurative treatments of design are most suitable for dress materials and domestic furnishings. The time has now arrived when the textile student, both designer and producer, must give more consideration to taste and judgment if he is to satisfy the demand for fabrics of smart and cheerful appearance.

THE JOURNAL OF THE TEXTILE INSTITUTE

Vol. XXI DECEMBER 1930 No. 12

PROCEEDINGS.

Examination in General Textile Technology

An examination in General Textile Technology in connection with applications for the Associateship of the Textile Institute took place simultaneously at headquarters, Manchester; the University, Nottingham; and the Royal Technical College, Glasgow, on Wednesday, 3rd December 1930. For the information of members and others interested, the examination paper, in two parts, is recorded as follows—

PART 1 (SECTIONS I AND V OF SYLLABUS)

10 *a.m. to* 1 *p.m.—3rd December* 1930

Candidates to answer THREE out of FOUR Questions in each Section of Part 1

Section I—Fibres, and their Production

(1) What physical properties represent "quality" in—(*a*) cotton; (*b*) wool for woollen yarns; (*c*) wool for worsted yarns; (*d*) flax ?

(2) Mention the chief sources of supply of—(*a*) flax; (*b*) hemp; (*c*) jute; and (*d*) ramie; and state the industrial applications of each.

(3) Write an essay on the natural fibrous materials commonly used for textile purposes, discussing the possibility of substituting some of these by other natural products or by materials manufactured synthetically.

(4) Discuss the influence of atmospheric humidity on the response of any one type of raw material to the spinning processes.

Section V—Analysis and Testing of Raw Materials, Yarns, and Fabrics

(1) Explain why two dyeings which match in daylight may differ in artificial light.

(2) Discuss the general principles of the sampling of raw fibrous materials, yarns, and fabrics. In making a strength test on a piece of cloth in both warp and weft directions, what is the most economical manner of taking the samples so that they fairly represent the whole piece ?

(3) How would you proceed to find out whether or not the stains on a piece of cloth were due to mildew ?

(4) Describe how you would proceed to test the suitability of—(*a*) dyed woollen yarns for bathing costumes; (*b*) dyed viscose weft for casement cloth; (*c*) dyed cotton yarn for a mercerised and bleached poplin cloth.

PART 2 (SECTIONS II, III, AND IV OF SYLLABUS)

2.30 *p.m. to* 5.30 *p.m.—3rd December* 1930

Candidates to answer TWO out of THREE Questions in each Section of Part 2

Section II—Conversion of Fibres into Finished Yarns

(1) Discuss the influence of the direction of twist, in the single and two-fold, on the character of the resultant yarn.

(2) What are the specific characteristics of wool yarns used for warp, weft, hosiery garments, and carpets ?

(3) What are considered to be the fundamental principles for drafting or attenuating textile materials in connection with the processes for preparing and spinning yarns ? What are the methods adopted for the purpose, in the different processes, and the reasons for the same ?

Section III—Conversion of Yarns into Fabrics, and Fabrics produced by Special Methods

(1) Why is it considered necessary to size warp yarns for weaving purposes ? Describe the methods of sizing—(*a*) cotton; (*b*) wool; (*c*) rayon yarns; pointing out why and how the methods you suggest best suit the natural characteristics of each.

(2) Cotton, wool, and linen yarns are supplied in various forms for the manufacture of—(*a*) woven fabrics; (*b*) knitted fabrics. Describe the advantages of each form for the particular branch of textile manufacture for which it is intended.

(3) Compare the characters of knitted and woven fabrics with regard to their structure, properties, and uses.

Section IV—Conversion of Fabrics into Finished Materials

(1) Write an essay on the waterproofing of textile fabrics.

(2) Describe the effects on cotton of—(*a*) boiling with dilute caustic soda for 10 hours and (*b*) treating cold with 25% caustic soda for a few minutes. How is the process of mercerising cotton piece goods modified when these contain, in addition, either (*a*) wool, or (*b*) viscose rayon ?

(3) Indigo is said to be a "vat" dyestuff. Explain the term, and give an account of the application of vat dyestuffs to any one of the following—(*a*) cotton; (*b*) rayons; (*c*) wool; (*d*) silk.

TEXTILE INSTITUTE ANNUAL COMPETITIONS
WOVEN FABRICS AND YARNS

Prize Distribution at the Institute, Saturday, 6th December 1930;
Mr. John Crompton in the chair.

Mr. Crompton, opening the proceedings, said—One regret which I felt during the early stages of my recent long absence from England was that I should be deprived of attendance at last year's prize distribution, but though Mrs. Crompton and I are being deprived of residence in sunny climes for this winter, we have the compensation of meeting with you all here to-day. I rejoice that the Committee's adjudication has enabled the Secretary to report a very high standard of achievement in this year's competitions, which I would remind you are intended for post-graduate students. The awards in these competitions, I believe, have proved the best form of testimonial attainable by young craftsmen who specialise in the structure of fabrics and woven design, and it is gratifying to be assured from time to time that, when suitable vacancies occur, candidates who have done the best work in the Institute competitions generally receive an appointment, thus getting a chance to prove their worth. I have pleasure in also acknowledging the great success which has followed the recently instituted competitions for fabrics and fancy yarns of novel structure. These give great scope for a student's inventive faculties, and I should like to see keen textile students not only inventing novel ideas in fancy yarns, but also testing and demonstrating the practical application of their ideas, by taking advantage of opportunities granted by our modern textile schools to encourage post-graduate students to weave and finish novel lengths of fabric designed for specific purposes. Weaving schools should invariably arrange to have sufficient length of cloth woven to show the draping or hanging qualities of any design judged by the Head of the College to possess sufficient merit to justify its actual display in any future public exhibition

Mr. Crompton next briefly referred to the Exhibition of Textile Designs and Fabrics which closed that day at the Art Gallery. His remarks are included on another page.* He then called on Mr. John Emsley, Past-President of the Institute, to present the prizes. In doing so he paid testimony to Mr. Emsley's great services to the Institute in connection with the grant of its Royal Charter and reminded his audience that Mr. Emsley had borne the financial burden of the petition for the Charter. Mr. Crompton also referred to the Adjudication Committee's excellent and painstaking work, and on behalf of the Institute thanked each adjudicator for his services. The list of awards and the Committee's report follows—

(A) COMPETITION—WOVEN FABRICS

First Prize (£40 and Certificate)—F. Ibbetson, (Bradford Technical College).
Second Prize (£25 and Certificate)—E. Cotterill (Manchester College of Technology).
Equal Third Prizes (£10 and Certificate each)—Miss M. Jackson (Burnley Municipal College) and C. Lord (Littleborough Textile School).
Prizes of £5 each—F. Taylor (Littleborough Textile School); G. T. Duckworth (Nelson Municipal Technical School); J. North (Bradford Technical College).

(B) COMPETITION—NOVELTY FOLDED YARNS

First Prize (£7)—W. T. Boardman (Blackburn Municipal Technical College).
Second Prize (£5)—C. Mayor (Blackburn Municipal Technical College).
Third Prize (£3)—H. Challoner (Blackburn Municipal Technical College).

(C) COMPETITION—NOVEL WOVEN FABRIC

First Prize (£10)—F. Ibbetson (Bradford Technical College).
Second Prize (£5)—E. M. Lawson (Manchester College of Technology).
Third Prize (£3)—A. Johnson (Leeds University).

*See page P205

(D) COMPETITION—WOVEN FABRICS (Special Students)

First Prize (£5)—J. Rae (Belfast Municipal College of Technology).

Second Prize (£3)—Miss I. Clark (Bradford Technical College).

Equal Third Prizes (£2 each)—J. Burgess (Macclesfield Art School) and H. Thornber (Burnley Municipal College).

In its report, the Committee states that the specimens of woven fabrics, as a whole, are of distinctly encouraging character to the promoters of the competitions. A really high standard of merit has been achieved, and a most satisfactory feature of the exhibits is that a good level of quality is maintained throughout. Many interesting features of interweave are presented and there is sound balance in design and colour and in the relative proportions of warp and weft selected in order to produce the desired effects. Marked improvement is shown in cloth structure considered in regard to effective binding. Great consideration has obviously been given to colour and texture in relation to the uses of the fabrics, but there is still room for improvement in classification and description. Floral design, in several instances, might have been improved considerably if the treatment had reflected more recent tendencies of style. Desirable restraint has been exercised in many directions, but more of the exercise of the adventurous spirit might occasionally have been indicated with advantage. Taking into account the considerable variety of cloths demanded, and also the varying facilities for production at the various training institutions, the specimens generally are of high merit even as representing the work of the most advanced students.

Adjudicators specially called in as assessors in regard to the commercial values of the cloths warmly commend the productions as a whole and state that commercial quality reaches the highest level for several years past.

The total marks of one competitor in the (A) Competition were reduced as a result of failure to comply fully with the conditions and of inaccuracy in costing.

Considerable ingenuity is shown by competitors for the prizes for novelty yarns, but complicated colourings should be carefully watched if liability to pattern in cloth or knitted fabric is to be overcome. Several competitors have erred on the side of coarseness of count of the yarns.

The total number of entries for the four competitions reached 55 as against 53 for the previous year, and the total prize-money awarded amounts to £145.

Mr. Emsley, having presented the prizes to successful competitors, to each of whom he addressed a few congratulatory remarks, said that Lancashire was always ahead. Things had altered, however, during the last few years. Circumstances over which we had no control had caused quite a different aspect to come over trading conditions. The last 20 years had seen a marked change in every respect. In the first there had been the great war, and our pre-war customers had found out that owing to the disturbance in the economic conditions of the world, it was difficult to get supplies from where they had been accustomed to getting them. Every country in the world had accordingly made up its mind that it would not be held to ransom by any other country and had said, "We will manufacture our own goods." These countries, generally, started with the lowest type of cloth which they manufactured by mass production, and now they had these particular fabrics in their own hands. If they had not been able to manufacture these goods economically they had put on a tariff, so that we could not send our goods into these countries on a competitive basis.

There had been a great change in the Far East, continued Mr. Emsley. We thought that western civilisation was superior to eastern civilisation and that there would have been no change in these markets, at least in our lifetime, but Japan and India had learnt the art of textile manufacture. We had had their students in Manchester; we had had their students working in our factories, and they had been able to buy the latest machinery and develop to a great extent on the brains of England and the cotton industry in particular. Having had the latest

equipment and scientific knowledge they had taken away a great deal of our mass production cloths.

It was always the same, said Mr. Emsley; if you read history you would find someone getting ahead and someone going down. In the woollen trade competition had come from Lancashire. Yorkshire used to manufacture poplins; then Lancashire thought of a way to manufacture them by mass production, so this trade had been taken away from Bradford. The "venetian" went the same way. Bradford had developed the manufacture of fabrics made of artificial silk. In these goods competition first came from the borders of Yorkshire, and afterwards extended to Lancashire to such an extent that Bradford was no longer able to compete as well as it did. Lancashire had not taken the woollen trade yet, they might try, but Yorkshire was prepared to fight for it.

Mr. Emsley expressed his pleasure at the fact that a man from Bradford had taken two prizes. Perhaps, he said, they would get a man from Lancashire to go to Bradford for prizes.

The last three years had witnessed something which had never been witnessed before in the world. Previous to that time they could make the earth yield as much raw material as possible because there was always a demand for it. During the last three years there had been more produced from the earth than could be consumed, and the prices of raw materials were lower than they had ever been in the history of the world. This had caused great uneasiness. We had a long struggle before us. We had the raw material; we had the means of making manufactured articles and attractive articles too, but we must do so at a price which would create demand in proportion to the increased production of raw material. To his mind it was not a question of reconstruction, it was a matter of using the raw material in such a manner that the best value was secured from that raw material for the money. He maintained that there was always a market for the best stuff.

A hearty vote of thanks to Mr. Emsley for presenting the prizes and to Mr. Crompton for his services to the Competitions' Committee and in the chair was accorded by the meeting on the proposal of Mr. F. C. Porter, seconded by Mr. J. W. Pennington.

Mr. Crompton then said that he wished to ask the General Secretary to make a brief communication to the meeting and in doing so paid testimony to Mr. Athey's continued interest in these competitions and his help in the preparation of the Institutes's Annual Reference Collections of Fabrics. Mr. Athey, whose remarks were illustrated by a few selected slides, said—

Public taste in design, colour, and texture of textile fabrics is measured by popular response to movements of change in character and style of garments. It is probably too often supposed that these movements are mainly attributable to some mysterious directive influence moulding or even creating popular fashion. Substantially, however, outstanding changes are dictated by the need for adaptation to alterations in the general conditions and circumstances of life. The popularity of the motor car, progress in speed of travel generally, and the advances which remove barriers of distance, all have a definite influence on the character and style of wearing apparel. Social conditions and environment exert directive influences, while economic circumstances, conceivably, may limit even desirable changes. Change in conditions as to housing and dwelling-house equipment give rise to fresh requirements of fabrics for furnishing and general domestic purposes. Change, moreover, is not completely governed by considerations of requirement and demand. The position of supplies of raw materials may considerably alter the course and character of industrial output as, for instance, in the case of rayon. Developments in mass production and in rationalisation in industry, together with the advent of the multiple retailer, offer a prospect of limitation to the exercise of popular choice.

Fashion is often described as fickle, erratic, and uncertain. But although fashion may occasionally prove disturbing to big-scale industry, yet, on the

other hand, popular fashions often stimulate trade. In this connection, progress in inter-communication between countries is undoubtedly widening the field for mass production. Vogue, in its wider aspect, is becoming less and less peculiar to any particular country. It is obvious that similarity is becoming more widespread, and mass production must tend towards universality. It is difficult to imagine a more fascinating field for observation and study than that represented by the output of textile materials for wearing apparel. The vastness and variety of the field, the kaleidoscopic changefulness from season to season in respect of design, colour, and character of the fabrics, would suggest a confusing rather than a well-ordered state of progressive change. Whilst change is essential to progress, yet, in this connection as in others, sound progress is not to be secured by violent or revolutionary movement.

For several years past, it has been part of my duty to take a non-technical interest in the annual collection of current fabrics which the Textile Institute issues to the textile departments of the various technical colleges and schools. Tendencies, discoverable in the course of the work of selection, may develop or decline, and sound estimation of the possibilities of any marked tendency is necessary if advantage in this direction is to be secured. It is important to preserve a wide outlook as to tendencies, because the character of the productions of entirely different industries may easily be of significance to other sections. Changes in style of furniture, for instance, may open up fresh avenues for enterprise to the producer of accompanying textile materials. The motor car has given us the term "streamline," and the description has become applied to the design of many things besides motor car bodies.

In the exclusive section of the field an interesting movement observed recently may be mentioned by way of illustration of tendency appreciation. For a number of years past, what has become known as "companion" fabrics—a more or less plain fabric accompanied by a similar fabric with a more elaborate pattern or ornamentation—have secured a fairly substantial following. A more recent development attempts a form of combination of the two, frequently by the simple expedient of the introduction of a border. There is nothing new in the idea of a border. It is as old as the hills, and the native tribes in some countries know little or nothing else of cloth ornamentation. Yet, introduced for a particular purpose, the border may play a new part. (Here slides illustrating this development were shown.)

The movement I have endeavoured to indicate places increased responsibility upon the costumier and maker-up. The costumier's art becomes no longer confined to cut and fit, but imagination may be exercised in regard to the whole plan or scheme of the garment. I have to acknowledge indebtedness to M. Francois, of St. Mary's Street, Manchester, for facilities in the matter of photography and supply of patterns.

Students of design and structure of fabrics cannot give too close attention to consideration of the details of cloths which have stood the test of the open retail market. The textile departments of technical colleges and schools possessed of the Institute's Annual Collections can at least offer reasonable facility in this connection, which are the more valuable as the annual collections accumulate. In looking back over the period covered by the whole collection, interesting comparisons may be made and repetition noted.

A hearty vote of thanks to Mr. Athey having been accorded, adjournment was made for refreshment.

In the evening the exhibition of prize winning fabrics, albums, and yarns was visited by members of the British Association of Managers of Textile Works. A general discussion on the exhibits was opened by Mr. John Crompton, the founder of the Competitions' Fund.

Mr. J. W. Kenyon, in the course of the proceedings, spoke on behalf of the Association. He said that he considered the display was remarkably good,

especially having regard to the fact that the work was that of students, who had not always the best of facilities for production at the various schools and colleges. It was not to be expected that the equipment could equal the conditions of the industry itself.

Mr. H. Craven referred specially to the yarns section. "This exhibition," he said, "is showing new things which the industry wants, and surely more could not be said of the efforts of the competitors." The very fact that these yarns could be produced at a college or school indicated the enormous progress since the time when he took part in class work at a technical institution. He thought that the cloth exhibits in a large number of cases were exceedingly good, and it was obvious that more attention was now being paid to commercial requirements.

Mr. Fletcher Chadwick, the President of the Association, thanked the Institute for their invitation, and expressed his pleasure that there had been such an excellent response. He assured Mr. Crompton and the representatives of the Institute that the managers were deeply interested in the whole scheme. He thanked the Competitions' Committee of the Institute for their reception and hospitality, and Mr. Crompton suitably responded.

Lancashire Section

Luncheon Meeting at the Institute, Manchester, 14th November 1930, Mr. W. T. Boothman presiding.

INSURANCE IN TEXTILE WORKS

The lecturer at this meeting was Mr. Carl A. Linstow, of Messrs. Scholfield's Ltd., Manchester, and, in introducing him, the Chairman said he was sure the meeting was to have an interesting and useful paper. He called upon Mr. Linstow to speak.

Mr. Linstow, dealing first with the question of insurance against fire said that the problem the insurance companies had had to solve was the elimination of the element of gamble and to turn a precarious undertaking into a steady, rich and safe enterprise. The key to this problem was the law of averages—a simple idea which had linked every civilised country in the world into a network of insurance.

In the insurance business this country, said the lecturer, was supreme. This business of insurance, now successful and stable, had been managed by business men who had pinned their faith to ample reserves, trustee securities, small dividends and no business without a profit. Turning to the more technical side of fire insurance, Mr. Linstow described how rates had evolved on the basis of experience. Companies collected statistics and information from their misfortunes. The nature of separate hazards was ascertained and separate additional rates instituted so that now for complex cotton spinning mills, whilst rates are built up of units charged for separate and clearly defined hazards, these rates are nevertheless exceptionally low. The outcome of the pursuit of this policy was that every modern cotton mill is built to the highest insurance standards and so commands the lowest rates.

Mr. Linstow then traced the onset and outcome of the rates competition waged after the introduction of the "average clause," which meant that if you did not insure property to its full value you had to bear your proportion of any loss. The increased demands which this made in valuation fees and premiums to cover adequate insurance caused the cotton mills to investigate other types of insurance markets. Fierce competition began and has continued, so that a first-class cotton spinning mill built to the required standards can be insured against fire at a rate of not more than one shilling per cent. The lecturer here referred to the claims of the Lancashire Cotton Corporation that, as a combine, under good centralised control, and because their business would be handled in

bulk, they were entitled to better rates. He reported that they got good terms which through the action of the Federation might be extended in other directions. Rates might fall as low as ninepence per cent. in consequence.

Dealing with woollen and worsted mills, the lecturer pointed out that the rates for these were higher than for cotton mills, partly because their construction was not up to that of cotton mills and also because of lack of bargaining skill and ability. Various points were discussed, among them being those of lighting, waste, oils, height of building, and sprinklers; it was stated that the rates for woollen mills were higher than those for worsted mills. Rayon had not yet presented opportunity for scheduled rates but no doubt would do so in time.

The lecturer next enumerated the various insurances which any textile works usually carries. These are fire insurance, stock, workmen's compensation, engines and boilers, and standing charges and loss of profits caused through fire or breakdown. Considering sprinklers, the lecturer said they were, in his opinion, the greatest protection against fire loss ever devised. But in his view the discounts were fantastic and ought to be reduced to a level which did not indicate that sprinkler-protected mills produced no losses at all. This was not so.

Concluding his address Mr. Linstow pointed out that though insurance companies would fight hard for profitable business they united as one man in putting up rates for unprofitable business. Might there not be a lesson in this policy for the textile industry he asked.

DISCUSSION

Mr. F. C. Porter, opening the discussion, said he had been interested in insurance since his first year in business but the largest sum he had ever received was £20. He was not satisfied to use the word gamble and would like the lecturer to concur that insurance should not be so described. He did not think fire was "a risk" and he hoped the sprinkler rates would be reduced.

Mr. Frank Wright said he must congratulate the lecturer on keeping the subject elementary. Referring to water damage he considered that Mr. Linstow had treated this matter very fairly; it should be emphasised that insurance was best effected on replacement value.

Alderman Thornber raised the point of variation in values. Would present day value be given or that at which it was insured five or ten years ago.

Mr. W. T. Boothman said if the policy covered replacement value, then one had to rebuild and he thought in times like the present that was a disadvantage and that firms were better protected by covering to the full value only.

Mr. Linstow in reply said that referring to the objection raised to the term "gamble," he was quite prepared to alter it to "speculation." As far as water damage was concerned, it was a need that was almost a necessity that mills should have sprinklers. A good many insurance companies cover water damage merely to oblige. It did not pay but they wished to get clients to take out fire policies. In some cases it cost nearly as much to insure against sprinkler leakage as for the fire itself.

Referring to replacement insurance, Mr. Linstow said he had stated previously that for obvious reasons the insurance companies could not pay clients for a loss unless it was suffered. If a mill's value was 30s. per spindle and cost £2 10s. per spindle to replace, then if rebuilt the payment of replacement value was necessary and justified, but if the firm went out of business then it could not hope to obtain the extra £1 per spindle. The insurance company could pay the price of a new mill for an old, but could not give the price of a new one if rebuilding did not take place. He added that there were 99 losses of a moderate size to every one mill actually burnt out. If the roof or top floor was burnt, then the insurance company gave the replacement value. Fire values were really different from actual values. The insurance company took no notice of the state of trade; otherwise, why should £2 per spindle be given when it could be sold anywhere for 10s. and

under. The payment was based upon the cost of rebuilding, less cost of depreciation.

Mr. Boothman moved a vote of thanks to Mr. Linstow, which was carried.

London Section

On Wednesday, 15th October, a party of members and friends of the London Section visited the laundry of Messrs. James Bentley Ltd., at Wilmington, Dartford, Kent, at the kind invitation of the Managing Director. The party was received by Mr. Bentley and was shown round the works by this gentleman, assisted by Mr. Luckhurst. The visitors saw many interesting and ingenious machines for washing, cleaning, etc., and were considerably impressed by the care taken of the articles during laundering, etc. The laundry is situated in the midst of an orchard, and the welfare work conducted by Messrs. James Bentley brought forth many complimentary remarks. After inspecting the various processes the party was entertained to tea. A vote of thanks, proposed by Mr. E. B. Fry and seconded by Mr. Mason, was heartily accorded Messrs. Bentley for a very interesting and informative afternoon.

Discussion Meeting held at 104 Newgate Street, London, on Wednesday, 5th November 1930; Mr. R. S. Meredith in the chair.

SIMPLE TESTS FOR FIBRES, YARNS, AND FABRICS

The Chairman, introducing the lecturer, said that he had undertaken a big task but would no doubt confine himself to a section of the field. At the end of the paper, questions could be put.

The lecturer, Mr. A. Mason, said that he would deal mainly with silk and rayon. He first described the factors upon which the chief characteristics of a fabric depend. These were fibre properties, yarn properties, and the make, constitution, ornamentation, and finish of the fabric. Varying combinations of these factors produced the ever-increasing multiplicity of fabrics now offered to consumers. Fabrics put on the market, if entirely satisfactory, should be made for a specific purpose. It was imperative that the distributor should learn to distinguish the best fabrics from those which were inferior. Mr. Mason proceeded to describe three fabrics which he exhibited—a crepe-de-chine, a spun crepe, and a suede crepe—from the point of view of their "handle" and such properties or lack of qualities which might be the source of "complaints" subsequent to make-up or laundering. He showed how the constituent yarns of these fabrics and the manner in which they were woven determined such fabric properties as slip, rubbing, marking, water marking, and shrinkage. He next described other simple tests that might be applied—e.g. selvedge examination, creasing warp and weft way, surface examination, "skying," count of warp and weft, weave determination, yarn constituents and twist determination, and finally microscopic examination of fibres. To distinguish fibres, the microscope could be supplemented by burning tests. Yarn measurements for size or count were described briefly though the lecturer pointed out that such measurements involved technical knowledge and skill.

Discussion

The discussion which followed consisted mainly of questions of detail on various points made by the lecturer. The term "crimp" had admittedly many meanings and varied from one branch of textiles to another. Rayon "slipping" was mainly a matter of weave; too few yarns per inch was the cause and nothing could distinguish this deficiency. The Chairman said he wished to impress upon distributors the importance of knowing what use a fabric was to be put. Mr. Wigglesworth, proposing a vote of thanks to Mr. Mason, said he felt such discussions were most valuable. The vote was carried with hearty acclamation.

NOTES AND NOTICES

Textile Institute Examination

The next examination in General Textile Technology, in connection with applications for the Associateship of this Institute, has been fixed to take place on Wednesday, 17th June, 1931. At the recent examination, held on the 3rd December, a total of 13 candidates attended—9 at Manchester, 3 at Nottingham, and 1 at Glasgow. Communications to the Institute on the subject of the Examination suggest the need of further explanation. Candidature is limited to applicants for the Associateship whose qualifications have received approval up to the stage of examination in General Textile Technology. Passing of the examination completes the qualifications required for admission to the Associateship.

Woven Fabrics: Design and Structure

The exhibition of woven fabrics and yarns in connection with the Annual Competitions of this Institute, arranged for the occasion of the distribution of prizes on Saturday 6th December, proved of more than usual interest. As a whole the display represented a distinct advance in arrangement, and the fact that competitors had responded more generously than hitherto in the provision of draping lengths of specimens added greatly to the effectiveness of the exhibition. The event was a striking illustration of the progress effected in relation to the competitions scheme over the last few years. Possibilities of still further extension of the scheme are fully appreciated by the Competitions Committee, but the means available by way of prize-money are such as to impose limits in this connection. The prize list for the current year reached the record total of £145. It was generally conceded that the exhibits for the present year attained a particularly high level from the point of view of commercial value of the cloths produced. The Committee would heartily welcome further offers of prizes by individuals. Since the scheme was inaugurated by the Crompton Memorial endowment gift, there have only been two individual contributions of gifts of prize-money, and the Committee looks forward confidently to further assistance of this description.

Coming-of-Age Celebrations

The Committee concerned with arrangements in regard to the Institute's Coming-of-Age Celebrations, to take place in the latter part of April of next year, has already arrived at the stage of presenting several recommendations to Council. All members are urged to take a special interest in the event, which is officially regarded as offering an exceptional opportunity for advancing the prestige and for increasing the membership strength of the Institute. It is expected that an outline of the proceedings may be available quite early in the New Year. Meantime, arrangements are under consideration. The President (Lieut.-Col. B. Palin Dobson) is taking a most active interest in the preparatory work and it is hoped that the final programme will comprise arrangements well fitted to the requirement of the important occasion.

Library Requirements

A recent meeting of the Library Committee afforded an opportunity to discuss present needs and future development, as well as to record progress. Many members still appear to have overlooked the announcement of the preparation and issue* of a Catalogue of the Library Contents. At the same time the daily recourse to the books and periodicals now being made is very gratifying to those who have worked to convert a small nucleus into a useful organism even though it is yet small and handicapped financially. Despite the big problem of storage,

* To be obtained from the Institute. Post free 6d.

now a very real one, the Committee purposes to go ahead and 1931 is not to be a year of stagnation. Meanwhile members from time to time make welcome gifts of books, many being of the "out of print" class unobtainable elsewhere, and periodicals. One object in view is to complete sets of Textile Periodicals and gifts to this end would be specially valued. Members who can spare any of the undermentioned periodicals either in single issues or as bound volumes are requested to consider making a gift thereof to the Institute.

TEXTILE RECORDER: ISSUES REQUIRED

1890–1891	Vol. VIII	June, July, August, September, October, November, December, and January and February of 1891.
1891–1892	Vol. IX	May, July, and August.
1901	Vol. XIX	September, November, and December.
1903	Vol. XXI	April.
1914–1915	Vol. XXXII	July, November, and January and February of 1915.
1915-1916	Vol. XXXIII	February (1916).
1916	Vol. XXXIV	July.

TEXTILE MERCURY: ISSUES REQUIRED

1919	Vol. LXI	Nos. 1581, 1582, 1583, 1584, 1585, 1586, 1587, and 1605.
1920	Vol. LXII	Nos. 1622, 1625, 1627.
1921	Vol. LXIV	No. 1679.
1922	Vol. LXVI	Nos. 1711, 1712, 1714, 1715, 1716, 1717, 1718, 1719, 1720, 1721, 1722, 1723.

Institute Membership

At the November meeting of the Council, the following were elected to Membership of the Institute—F. T. Chadwick, Antwerp Mills, Armley, Leeds (Worsted Manufacturer); E. D. Faulkner, "Colne Forge," 119 Dowson Road Hyde (Overlooker, Winding and Warping Department, Cotton Mill); G. W. Hemingway, 6 Springfield, Hipperholme, near Halifax (Foreman, Worsted Spinning); W. Holt, "Holme Lea," Draycott Road, Tean, near Stoke-on-Trent (Manager, Smallware Manufacture); W. J. Irvine, 2 Lanfine Road, Paisley, Scotland (Dyer); H. F. Lilburn, 254 Kimberley Road, Leicester (Hosiery Manufacturer); R. I. Martin, Engineering Laboratory, British Thomson-Houston Co. Ltd., Rugby (Insulation Engineer); W. H. Matthews, Industries and Manufactures Department, Board of Trade, Great George Street, Westminster, London S.W.1 (Civil Servant); W. H. Walmsley, 3 Turton Road, Bradshaw, near Bolton (Scutcher Tenter); E. Wildt, Wildt & Co. Ltd., Tudor Road, Leicester (Knitting Machine Builder).

REVIEWS

Textile Mechanics and Heat Engines. By A. Riley and E. Dunkerley. Published by Sir Isaac Pitman & Sons Ltd., London (286 pages, 15s. net).

This is a text book specially prepared for those who are studying to the syllabus in Textile Mechanics and Textile Engineering of the Union of Lancashire and Cheshire Institutes and the City and Guilds of London Institute. It is unfortunate that the authors, in those sections which deal exclusively with textile machine problems, have restricted their illustrations to examples of cotton spinning machinery only. There are no references to machines for warp preparation, weaving, or other branches of the industry. Fully 50% of those who attend textile classes will be primarily interested in such machinery.

The book would be of higher value had it devoted the bulk of its space to the mechanics of textile machinery and given less space to prime movers. We are of the opinion that there is too little of the "textile" to warrant the use of the title "Textile Mechanics." No doubt this want of proportion is due to attempting to cover too wide a field of work in one volume, and endeavouring to embrace a syllabus which is far from perfect.

The book contains 13 chapters and the first seven cover the subjects of transmission of motion, forces, work done, friction, simple machines, motion, and elasticity. The latter half of the book has to do with hydraulics, heat, gases, steam boilers, steam engines, internal combustion engines (including Diesel engines), with just a reference to electrical drives and steam turbines. There are 275 diagrams used to illustrate the text and these are very well prepared for the purpose. About 60 of this number refer to various applications found in spinning machines. The rest are of the general type to be found in any text book of experimental mechanics and heat engines. One hundred and fifteen fundamental laws and equations are quoted in the text and in most cases the mathematical deductions for these are shown. Each chapter is concluded with a set of questions with answers, and in general these are of a more elementary nature than the textural matter would lead one to expect. There is a demand for original works dealing with mechanics applied to textile machinery, which this volume to some measure supplies. But in the reviewer's opinion the textile student's chief concern is to secure a thorough knowledge of his own materials and machines as early as possible in his career, and for this reason it is difficult to see why, for example, the question of elasticity has been confined to the stretching of rubber, steel wire, etc., without reference to the behaviour of any one textile material when placed under tension or compression. Figure 40 on page 28 requires the addition of a simple carrier wheel between the front and back roller wheels. Question 8 on page 108 seems to require additional information before the question can be solved, and on pages 206-207 one becomes a little doubtful if the blow-through cock C for the water level gauge has been correctly identified. It is undoubtedly the magnitude of the task undertaken by the authors that has caused the lack of balance noted above. This lack of balance masks the volume of useful exercises and examples given in the various sections and in these the book has something of real value to offer.

J.R.

The Furnishing Soft Goods Department. By W. A. Gibson Martin. Published by Ernest Benn Limited, London (148 pp. and index. 15s. net).

To those engaged in the textile trades this will be found to be a very valuable book. Although intended, of course, for the furnishing section much of it will be useful for all branches of the industry, both in the details given for stock buying and stock keeping and in the general hints on salesmanship, window dressing, and the like. The ultimate phase in the production of textiles is their disposal and it is incumbent on every section to act in unison, to endeavour to bring together the shopman, the public, and the actual producer. The science of salemanship has advanced enormously of late years, owing to fierce competition, the spread of artistic taste among the general public, and the continual changes of fashion in furnishing resulting in the multiplicity of new fabrics ceaselessly put on the market. Let the manufacturer then take into partnership the shopkeeper and his staff, recognising his and their common interest.

The author's remarks on organisation are very thorough and are generally sound; his system of stock-keeping, of costing, and of workshop economy are all excellent, and although generally followed by large high-class business firms, contain many hints which might be found valuable in every establishment as making for greater efficiency. Stress is very justly laid on the advantage of salesmen being given the opportunity of acquiring knowledge of the actual manufacture of the goods they have to handle, and it may be added that facilities should be given for promising youths to visit the Continent from time to time and thus enlage their view.

As to the choice of salesmen, the author commits himself to the opinion—"The most useful salesmen as a general rule are those who have served their apprenticeship to the soft goods department" and to this we must take exception. The best apprenticeship is that to a general furnishing house where he has "to serve through" and gain an insight into every branch; he can specialise afterwards. In the writer's experience a tactful remark about the carpets or the wall decoration, or a suggestion showing his knowledge of period furniture has often resulted in a small order growing into a large one. Again—very little is said in the book about draughtsmanship. Every salesman should be able to draw simple forms. A rough sketch in pencil on a scrap of paper in the showroom, or in charcoal on the wall of an unpapered room has often given more confidence to a customer than

any amount of talk. Some of the questions proposed for a prospective salesman seem to be more for the buyer, especially the names and addresses of firms which deal in particular goods. With these slight exceptions we must give the book an unqualified welcome as the most complete technical trade work which has come under our notice. G.B.

"Künstliche Organische Pigmentfarben." By Dr. C. A. Curtis. Published by Verlag von Julius Springer (225 pages and Index. Price 22.50 R.M.).

There are very few modern text books dealing in any adequate fashion with the nature, production and application to industry of pigments and lake colours. The enormous ranges of inorganic and organic chemicals, which are drawn upon to produce colouring matters of this kind, render the task of the author of an adequate text book a particularly difficult one, and if regard is had to the chemical and physical phenomena involved in the manufacture and use of these bodies it becomes increasingly evident that no one text book is likely to do justice to all the phases of the study. With these reservations in mind, it must be said that the book under review is a very useful contribution; and, therefore, there is some satisfaction in recording that the book has now been translated into English. The subject matter is divided into six parts—the first being the production of organic pigment colours; the second, the application of pigment colours; the third, the newer patent literature on organic pigments; the fourth, theoretical considerations; the fifth, analytical; the sixth, a table of the coal-tar dyestuffs in the pigment colour industry together with a survey of patents, and index. The principal value to the lake chemist and manufacturer will probably reside in the collection of information regarding the more recently introduced colouring matters, and in the section dealing with the application of these products where a large number of mixings and recipes are probably valuable as indications of industrial methods rather than as instructions to be followed with absolute rigidity. Reference is made, for example, to the new Fanal colours, which are produced by the interaction of colouring matters with complex compounds of phosphotungstic acid, and are remarkable for their fastness to light.

The theoretical part as well as the analytical are inadequate. Little attention is devoted to the very important question of light fastness, and very little is said about the nature of the physical and chemical changes which take place under the influence of light and exposure. In spite of these defects, the author has covered a ground not recently traversed by the writer of text books, and there can be little doubt that the volume will be indispensable for some time to those engaged in the pigment industry. F.S.

Ornamentation and Textile Design. By Aldred F. Barker. Published by Methuen & Co. Ltd., London (31 pages and xciv plates. 15s. net).

By producing this volume Professor Barker made a notable addition to the list of publications dealing with "textiles" and the design thereof. I say "notable addition" not merely on account of the fact that the book contains nearly 100 photographic illustrations and drawings, but because in this work he puts forward very strongly the vital necessity for the designer to look beyond his immediate locality and sphere of work for means of expression. The necessity to "live" in the fullest sense of the word, seeking inspiration in everything both actual and abstract, and alert to the changes both in styles of art and modes of living. His object is obviously to stimulate the designer's mind to higher expression and is not concerned with technical problems.

To the immature mind he gives a lead in the manner of seeking after qualities of good design by showing photographs of good examples of many phases of art. An illustration of the value of the intelligent appreciation of form and movement is conveyed by the photographs of "barley" in plate viii and the authors design based on it in plate x. The likeness to "barley" may or may not be desired, but the vital (abstract) quality of movement and swaying in the wind has to be interpreted absolutely in Professor Barker's severely conventionalised design. From such illustrations as these we may turn to "Horse Brasses" or "Gothic Architecture" for inspiration, or even to "Modern Painting" and "Cubism." Along with the text, which in Chapter VII gives "Psychology in design," the author has made out a very sound case for his contention that the designer must be a most alert and intelligent being capable of enriching his mental outlook

and forming a storehouse of ideas from the varied fields such as indicated in this book. The creative artist will see much to interest him in this publication.

P.O'B.

Die Spinnerei in technologischer Darstellung. By Edw. Meister. (Berlin, 1930, pp. 243, Figs. 223; J. Springer; Mk. 15.50.)

Books on spinning are gradually evolving. Until about 1890 they did little more than teach simple arithmetic and filled many pages with long-division sums. Then they began to describe in minute detail the construction of motions and machines, and many of them almost lose sight of the fibre for the mechanism. There can be no doubt whatever that we have reached a period when students will inquire more after the behaviour and fate of the fibre in any given operation than after the differences in design of the machines sold by various makers. Prof. Meister's book is, therefore, to be welcomed because it deals with principles and restricts the description of mechanisms to reasonable proportions.

The book is based on one written by the late Prof. Rohn 20 years ago, and is described as a second edition. It has been so completely revised, however, that the perpetuation of Rohn's name on the cover and title page is surely to be regarded mainly as a tribute to his memory.

The chapters are arranged in the following order—(1) Principles; (2) Properties and testing of yarns; (3) Special branches of spinning, (*a*) cotton, (*b*) wool and related fibres, (*c*) bast fibres, (*d*) silk, (*e*) rayon, (*f*) asbestos. Sections that will be of particular value to English readers are those dealing with high drafting and waste spinning, for cotton, and that on the mule spinning of worsted.

One of the best features of the book is the number of very clear diagrams. The text, however, is rather condensed and would gain in value to students if there were more headings and sub-headings. For example, mule spinning succeeds ring spinning (p. 82) without a break and a reader turning over the pages in search of the mule is guided merely by the pictures. The binding is good and there is an adequate subjects index.

W.

Praktischer Leitfaden zum Färben von Textilfasern in Laboratorien. By Ed. Zühlke. (Berlin, 1930, pp. 234; J. Springer; Mk. 9.50.)

The author of this useful book is a member of the staff of the Dyeing and Finishing School, Krefeld. He provides a comprehensive course of experiments for students in modern forms of dyeing, covering most of the important classes of dyes and, as fibres, cotton, wool, silk, and rayon. The chief omissions are the mineral colours (chromes, khaki, etc.), whilst Turkey red dyeing is dismissed in a paragraph or two, but the gaps are of course in keeping with the air of mystery that envelops these processes. The level dyeing of viscose rayon with direct dyes is recognised as a difficult operation, but Whittaker's work and the brochure issued in 1927 by Messrs. Courtaulds are only mentioned in a footnote to p. 202. There should have been time in the last year or two to try the capillary rise and temperature range tests in a few students' classes and find room for them in a book dated August 1930. Incidentally, Mr. Whittaker may scarcely recognise his name in the German spelling.

The book is issued in stiff paper covers, without indexes, but the contents pages are perhaps sufficiently detailed. Unfortunately it is rather costly for students.

W.

Die Praxis der Bleicherei. By Prof. E. Ristenpart. Published by M. Krayn, Berlin, W. 1928. (Pp. 291. R.M. 30).

This book is the fourth volume of the Chemische Technologieder Gespinstfasern" and deals with the bleaching of cotton, linen, hemp, jute, ramie, paper, rayon, straw, wool, and silk, although as one would expect, two-thirds of the book deals with cotton bleaching. In many ways the book is an excellent compilation, the section on chemicals containing much useful information, but the sections on machinery and processes read too much like a catalogue. One misses the discussions on the rationale of processes which one expects to find in German technical books. In one sense this is a pity as such discussions are always stimulating even if, as they sometimes are, misleading. Nor can one say that the book is rich in *Kunstgriffe* which enables one factory to work a process more successfully than others. The machinery and processes, however, are described in great

detail with copious illustrations, so that while the experienced technical man may not find much help in processes with which he is familiar, he will find the description of unfamiliar processes helpful. The chapter on the newer bleaching processes is disappointing and the section on the testing of bleached goods could be considerably improved. K.

GENERAL ITEMS

Design and The Cotton Industry

Several expressions of opinion upon the Exhibition of Designs for Fabrics held during November and December at the Manchester Art Gallery, were received too late for inclusion in our November issue. They are printed below in the belief that each contributes something to the solution of the problem of devising means whereunder art students and fabric designers may be trained in such a way as to afford the best results, not only to the industry but to themselves. They are, of course, expressions of the opinion of their authors only and are not necessarily those of the Institute.

Mr. John Crompton, speaking at the Institute,* said—

I think it is not out of place for me to make some reference to the Exhibition of Textile Designs and Fabrics held at the Art Gallery in Mosley Street, which closes to-day. I was unable to visit it before I read some criticism in the Press, but on comparing this with my own judgment at a later date, I could not help feeling that the critics had overlooked the fact that the exhibit was more or less a hasty collection made at short notice, which includes the work of many young students who have not received any instruction as to how painted designs require to be modified to represent the effect that can be produced in actual weaving or printing. I very strongly urge that ample notice should be given to Art and Textile Schools of future exhibits, and that they be required to submit designs not only for specific purposes, present-day taste, and as suitable for definite markets, but to be judged from their effective as well as commercial point of view. Of course, I am aware that it would be too costly a matter for schools to have rollers engraved and designs actually printed, unless they were convinced that they would be taken up commercially, but I consider the effect of the design when applied to fabric could be more nearly represented than is at present usually the case Then, again, the student should be asked to indicate the particular market, country, and purpose for which each design is intended, so that it could be judged whether the colours used are too vivid or the design too crude, which, judging from the present exhibit, would probably be the case in very many instances.

I suggest that when Art Schools submit designs for wall decoration, these should be mounted on sectional cardboards, which can be assembled and which enable them to be displayed from as near as possible the position for which they are intended. I further suggest that painted designs intended for upholstery or curtains should be on flexible untearable paper, to allow it to be placed in suitable positions for proper adjudication. As regards the general merits of the Exhibitions as a whole, I beg to submit my own considered opinion that there is ample justification for the criticism that our Art Schools are not in sufficiently close touch with periodic changes of fashion, in either dress or decoration, and if they are to provide a constant supply of students of valuable aid to industry, the art training should also embrace a course of lectures in modern fashions and specific styles of design especially suitable for different markets.

I also consider it advisable that even for an exhibition of the character of the one held in the Manchester Art Gallery, all designs sent in should first of all be submitted to a Selection Committee, and only those displayed to the public which, in the Committee's judgment, serve the purpose for which the Exhibition is intended. I trust steps will immediately be taken to provide for future exhibits under such guidance and conditions as shall bring about a real liason between Art Schools and those controlling our great textile furnishing and decorative trades.

Mr. T. C. Dugdale, Design Department, Tootal Broadhurst Lee Co. Ltd., writes—

While there was a considerable amount of promising work in the Exhibition, it was, as a whole, rather disappointing because most designs seemed to be merely academic making of patterns rather than designs with a specific intention, and a large amount of space given to Technical Colleges, which showed what were merely exercises in cloth structure, tended to make the Exhibition rather uninteresting in appearance. Fitness for purpose was inclined to be of secondary importance, and the subject matter, or motif, of the design was apparently more present in the student's mind than the purpose for which the material might eventually be used, and there were many designs with too

* See page P193.

many motives to be really successful for their declared object. The colour sense displayed was generally rather poor, lacking brightness and inventiveness, and in many cases colour schemes were definitely in bad taste, both for dress and furnishing, and a criticism of form is that drawing was rather weak and inclined to be somewhat commonplace even though many of the motives were enterprising. It was, for example, quite amusing to find designs made of ballet dancers, elephants, street scenes, landscapes, etc., though when such ideas are employed they should not, as a rule, be treated pictorially, as most of them were inclined to be, but should be more definitely abstract.

Some of the most interesting exhibits were those in which students block printed pieces of fabric with their own designs, because here the very limitations which a reproductive process enforces made the students economise as to number of colours employed, and for that reason alone results were generally more happy. The exercise of printing many repeats of a design should teach a feeling for fitness for purpose, and also tends to show clearly any faults and drawbacks, and also any qualities, the design may possess.

There was painly a regrettable lack of consideration of fashion, both in designs labelled for dress and those for furnishing materials, and a good many of the designs shown seemed to belong, not so much to 1930, as to a period between 1890 and 1900. It seems clear, therefore, that considerable improvement in this direction is necessary if the Schools of Art (and this is their concern more than that of the Technical Schools) are to train their students in the right way—it is essential that touch should be maintained with the vogue of the day if progress is to be achieved. Development of colour sense (fitness of colour for purpose is just as important as suitability of design), and at the same time cultivation of taste should be most important considerations, and in cases where students obviously lack (after a reasonable trial) any sort of taste for style, or colour, it will be sounder in the long run to discourage them from carrying on as art students at all.

It might be suggested that considerably closer touch between members of the industry, and Schools of Art in the area, should be attempted in order that, on the one hand, the schools would realise the needs of the industry, and the kind of designs that fashion calls for, and also, that what criticism of the students' work the industry makes should be definitely constructive, and of a nature rather to encourage than discourage. It will be quite impossible to build up any school of design in this country that will be of value unless considerable help is given by the industry and unless a definitely sympathetic attitude to the efforts of the Art School is maintained. It would be distinctly unfair to judge the Exhibition of work as that of fully fledged professional designers, but at the same time it would be even more foolish to do nothing in the way of attempting to point out faults. It should not be forgotten that for the cultivation of flowers plenty of sun and judicious watering are important, but it must not be lost sight of that you cannot grow the best flowers in surroundings which are quite unsuitable, and these points are probably mostly to blame for many of the faults and drawbacks referred to above.

Mr. S. Ibbotson, Manchester, writes—

After several visits to the Exhibition, I feel very disappointed with the general standard of work submitted—so few of the designs give satisfaction either in form or colour. There is certainly no lack of ingenuity shown in the matter of ideas and treatment, but one can hardly say they would enhance the value of any fabric to which they might be applied. I got the impression that there is open revolt against the accepted principles of good design, and a very definite attempt to ignore tradition. Mill chimneys and telegraph poles certainly have their places in the scheme of things, but they do not seem appropriate as motifs in a cotton print design The colour schemes generally are either crude or so "muddy" that one imagines the designer working continually under grey skies and getting little real pleasure out of his work.

With reference to the block printed hangings shown, they may be considered a triumph from the students' point of view as he has many difficulties to overcome, but the result can hardly be considered as entirely satisfactory. Had the difficulty of laying the blocks to avoid joinings been appreciated, no doubt that would have influenced the character of the design and misfitting would have been less in evidence.

THE

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PROCEEDINGS—NAME INDEX

In this Index (C) indicates that the matter is the subject of a Communication, and (R) that the matter is a Review.

PROCEEDINGS—SUBJECT INDEX

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TRANSACTIONS AND INDEX

THE JOURNAL OF THE

TEXTILE INSTITUTE

TRANSACTIONS

1—A NOTE ON THE PHYSICAL RELATIONSHIPS OF CRIMP IN WOOL

By S. G. BARKER, Ph.D., D.I.C., F.Inst.P., and M. H. NORRIS, M.Sc.
(British Research Association for the Woollen and Worsted Industries)

It is well known that the wool of certain breeds of sheep, particularly the Merino, presents a crimped appearance when in the greasy state. The cause of this manner of growth, and the reason why the size and shape of the crimp waves should vary, is unknown, but the fact that the type of crimp is often taken as a guide to the fineness and spinning qualities of wool leads to the assumption that there must be some connection between the crimpiness and the quality of the wool. Various papers in the literature[1] describe measurements attempting to find a relationship between the number of crimps per inch and the diameter of the fibre. Although most of the authors conclude that there must be some sort of relationship between these two variables, no direct variation has been found, while Davenport and Ritzman[1] concluded that "on the whole our data yield support to the view that (within limits) there is no necessary relation between crimp and fibre diameter." Duerden[2] has recently published an interesting paper on the relation of crimp and of fibre diameter to the commercial quality numbers of Merino wool. Wool standards have been worked out, and it is claimed that using selected wools it is possible to predict commercial quality numbers from fibre thickness or from the number of crimps per inch. However, so many types of wool (even when the attention is confined to the Merino) have to be classed as anomalous that the work of elucidation of the laws governing crimp in wool still remains to be executed.

Examination of a wide range of wools shows that many definite types of crimp and curl occur. Thus a single fibre may be in the form of—

(1) A simple spiral which may be circular or elliptical.
(2) A spiral which at a certain period of its growth has reversed its direction of rotation.
(3) Uniplanar waves.
(4) Uniplanar waves in which the plane is gradually rotating along the length of the fibre.
(5) Combinations of the above in the same fibre.

Examples of these types are shown in the photographs of Fig. 1. Beside each lock of wool are seen two or three fibres that have been taken out from the lock.

(*a*) and (*b*) illustrate the corkscrew curl. They are from a Wensleydale sheep. The arrow in (*b*) indicates the position of the change of direction of rotation in this lock.

(*c*) is a lock of wool from a Merino sheep, and is a good illustration of uniplanar waves. The small piece of the lock that has been detached from the rest clearly shows that all the crimp waves are in the plane of the paper on which it is lying.

(*d*) presents a different appearance from the lock (*c*), although it is seen from examination of the single fibres that all the crimp waves of a single fibre lie in one plane. The undulating appearance of the lock is due to the arrangement of the fibres relative to each other.

(*e*) shows fibres illustrating uniplanar crimp in which the plane of crimping rotates along the length of the fibre. On the fibre marked, the plane of the crimp has turned through 180° between the regions (*A*) and (*C*). The crimp at the region marked (*B*) was just as distinct as at (*A*) and (*C*), but it is not seen in the photograph, because the plane of crimp is at an angle to the plane of the paper.

(*f*) shows a lock containing fibres with uniplanar crimp at the region (*A*), and a tendency to corkscrew formation at the region (*B*).

(*g*) is a lock of wool in which the size of the crimp waves shows a distinct variation in different parts of the same lock.

The subject matter of the present communication is presented under two headings—

(1) The relationship of cross-sectional area to the number of crimps per inch.

(2) A physical explanation of the phenomena of crimp.

SECTION I—THE RELATIONSHIP OF CROSS-SECTIONAL AREA TO THE NUMBER OF CRIMPS PER INCH

EXPERIMENTAL

Method of Measurement

The results of the experiments here recorded were obtained by measuring the number of crimps per inch of unstretched wool. The reciprocal of this number is termed the wave length. The wool was measured against a steel ruler, first in the lock, and then individual fibres were taken from the lock and measured in the same way. Ten fibres were selected, which showed the same number of crimps per inch as did the lock, and were mounted without tension across a microscope slide. The mean diameter was found by taking the arithmetic mean of five measurements of diameter taken at equal distances along the inch of fibre across the microscope slide. It was found that five measurements were sufficient, for if taken at equal distances along the fibre they gave the same mean result as a series of twenty, or even more, measurements along the same fibre. Measurement was carried out by means of a micrometer scale in the eyepiece of a Leitz microscope. The magnification used was ×553, and one large division of the micrometer eyepiece was found to be equal to 0·000945 inches. Measurement was made to the nearest tenth of a division (i.e. one small division or 0·0000945″). It was found convenient to mount the fibres in glycerine, and furthermore this medium gave results which were identical with those obtained when the same fibres had first been measured in air.*

* It has been found by King (*J. Text. Inst.*, 1926, **17**, T53) that glycerine is equivalent to dry air in its effect on the change in size of a fibre with varying humidity conditions.

Various kinds of wool were used from widely different sources,* and in all cases the wool was in the natural grease, unscoured and not treated in any way previous to examination. The South African and Tasmanian wool was all Merino, but the Australian and New Zealand included some cross-bred.

From considerations arising from the results of these measurements (see later) it is evident that the problem is sufficiently interesting to warrant a more precise method of measurement. A simple apparatus has therefore been set up in which amplitude as well as wave length can be measured with comparative ease. This apparatus consists of a projection lantern which is fitted with a 6 in. R.R. lens. Crimped fibres in the lock, or singly, are placed in contact with a process screen (150 squares to the inch), and an image is projected on to a white surface at a distance of some 4 or 5 feet from the lens. This gives a magnification of roughly $\times 10$. The definition is good, and it is a simple matter to measure amplitude as well as wave length by counting the squares on the projected image of the process screen. The exact size of these squares can readily be ascertained by microscopical examination with a micrometer eyepiece, and the measurements of amplitude and wave length thus converted to absolute units.

For the determination of cross-sectional area we have substituted the method described by Barker and Burgess,[3] the advantage of this method being that the mean cross-sectional area and circularity ratio of a comparatively large number of fibres can be determined within a reasonable time. The results obtained using this more elaborate method of experiment will be the subject of a later communication.

Irregularity of Crimp Waves

Examination of a large number of locks of wool and the measurement of the number of crimps per inch revealed the fact that in almost every case the size of the waves increases along the staple from root to tip. In some locks this effect is very marked, the crimp being small and close near the sheep's body and larger and looser towards the tip of the lock. In other well-crimped locks the crimp appears at first sight to be uniform, but on closer examination this same progressive increase in the size of crimp is apparent, so much so that rarely was it possible to find a length of fibre longer than an inch in which the waves were not measurably smaller at one end than the other. The above observation refers to well-bred, regularly crimped wool.

The reason for such a phenomenon is not obvious, although it is possible to speculate upon the causes that could produce such an effect. In the first place the wool is most compact near the sheep's skin, and is to a certain extent protected from disturbance by the outer wool. It is to be expected therefore that the root end of the lock would show the wool in the form nearest to that in which it was moulded as it issued from the follicle, while towards the tip end of the lock mechanical attenuation due to frictional and to other extraneous forces would come into play. It is well known to manufacturers that crimp can be at least temporarily removed by wetting a fibre and allowing it to dry in a strained position, while experiments by one of us (M.H.N.) on stretching without wetting, showed that the size of the crimp is reduced by such means, although the effect is not permanent. In these experiments wool fibres were measured for the number of crimps per inch

* Samples of Tasmanian fleece wool (all from the same flock), South African, Australian, and New Zealand wool supplied to us in the greasy state by manufacturers, and South African greasy wool sent to us direct from the breeders.

and then extended until the crimp just disappeared. They were maintained in this position for two or three days. They were then released, and immediately measured again for crimp. In all cases it was found that although the fibre regained a fairly regularly crimped appearance as soon as the strain was released, the number of crimps per inch was reduced. For example, 20 became 16 and 7 became 3. Measurement after the fibres had been allowed to rest in an unstrained position for several days still showed this reduction in the number of crimps per inch. They were then left to rest for a period of five or six weeks and again measured. These final measurements showed that in every case the number of crimps per inch was the same as before stretching, although possibly the crimp was not quite so regular as formerly in that it did not lie all in the same plane. It is quite feasible that wind and rain produce conditions not dissimilar from the above.

Observations of a marked difference in diameter of fibres at the root and at the tip has been recorded in the literature. McMurtrie[1] and Bailey and Engledow[4] agree that in general the diameter of the fibre towards its tip is less than that towards the root, although in the case of sheep shorn when they were known to be in a pathological condition the reverse was true. Bailey and Engledow observed, when watching a commercial wool sorter at work, that "the sorting was largely based upon an examination of the base of the fibres . . . but that the presence of any obviously coarse fibres at the tip was sufficient to put the wool in a low class." It is suggested by them that observations near the tip might be more trustworthy, as this part of the lock is grown in the summer when the sheep is usually in its best state of health.

Many locks showing truly irregular crimp are encountered; for example, a region of small tight crimp may be found to occur in the middle or at one end of a lock which shows larger crimp elsewhere (Fig. 1g). Such a result is thought to be due to the sheep passing through a pathological condition or a period of drought. Again, the shape of the crimp waves is by no means constant from one lock to another, or even throughout the same lock—amplitude probably varies almost as much as wave length, and although so far we have been unable to obtain any reliable measurements of this quantity, our new method of experiment provides the means (see above).

A few measurements have been made with fibres from a lock similar to that shown in Fig. 1g. Examination of the number of crimps per inch showed part of the lock to contain six and part twelve crimps per inch respectively. The mean cross-sectional area of fibres taken from these two regions were approximately in the ratio of 2 to 1, as would be expected from our rule (see later). Extension of inch lengths of unstretched fibres showing 6 crimps per inch, until the crimp just disappeared, gave an increase to 1·24 inches, while similar treatment of fibres showing 12 crimps per inch showed an extension to 1·23 inches. This result is interesting in that it shows that measurements of crimpiness by this method of extension, which has been used by some workers, can be valueless for giving any indication of the size and shape of crimp.

A further very suggestive and interesting observation has recently been made, and communicated to us by Mr. Lefroy, of the Cranmore Park Stud, Boolardy Pastoral Company Ltd., Walebing, W.A. A lock of wool, similar to that shown in Fig. 1g, from a sheep shorn on the 1st October 1928 after the wool had been allowed to grow for twelve months, shows in all thirty

crimps along its length. The size of the crimp waves is not constant throughout the lock, but falls into three distinct regions—in the middle one the crimp waves are smallest, the tip region showing larger waves and the region at the root having waves even larger. The sheep which grew the lock of wool was under experimental observation, and the length of wool grown in each period of four months during the twelve months growth was as follows—

1st October to 1st February	1·16″ (tip end)
1st February to 1st June	0·81″ (middle portion)
1st June to 1st October	1·31″ (root end)

These three lengths correspond with the crimp regions mentioned above, and the interesting point is that each region shows *ten* crimps; that is, the length of the crimp wave in each region is 0·116″, 0·081″, and 0·131″ respectively. The inference from this observation is that the formation of crimp in wool is a periodic function of time, and that the number of crimps produced per month is constant even though the length and thickness of fibre grown

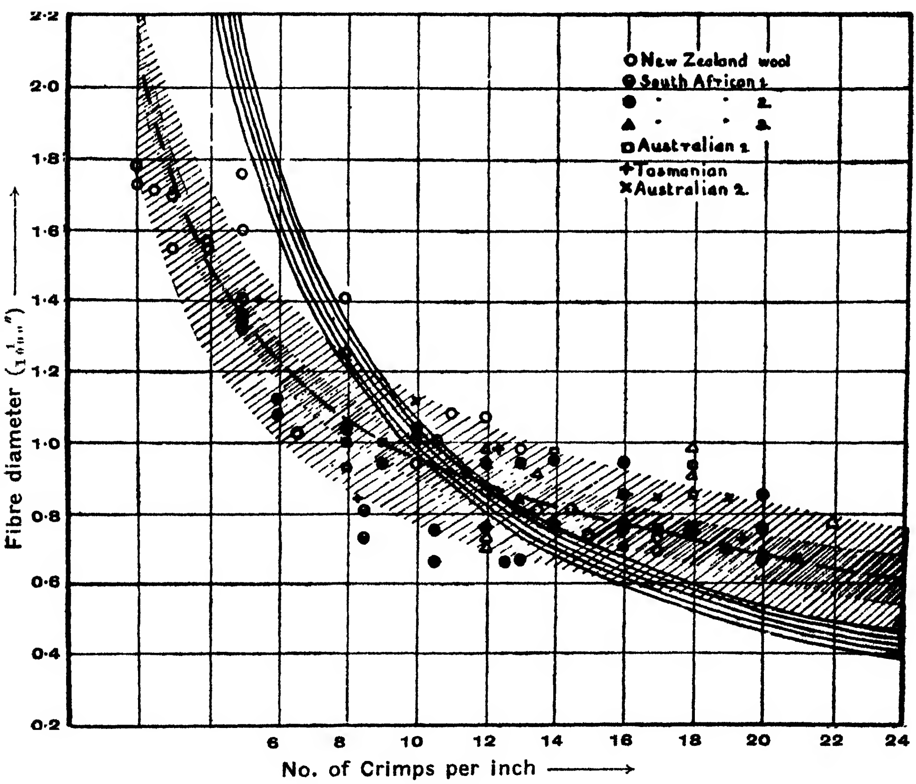

FIG. 2

per month may vary with the climatic or other conditions existing during the period. Mr. Lefroy further points out that his observations lead to the conclusion that the number of crimps per inch produced in a given time varies with the individual sheep under observation. One sheep will produce ten crimps every four months, while another will produce perhaps eleven

or twelve. Although these solitary observations afford insufficient evidence upon which to generalise, it is nevertheless of great interest that these records have been made, and they lend support to the conclusions reached in this paper.

Experimental Data

Previous authors including Duerden (*loc. cit.*), have attempted to relate the number of crimps per inch with the so-called diameter of the wool fibre. One of the chief objects of our investigation was to discover whether or not so-called "diameter," that is, fibre width at a point, is the quantity we really ought to measure. It is known that the wool fibre is a three dimensional body of irregular shape, only approximately cylindrical; and further, the "cylinder" is usually found to be flattened so that its cross section is elliptical.

The values we obtained appear in graphical form in Fig. 2. Fibre "diameter" (in thousandths of an inch) is plotted against the number of crimps per inch. The five parallel curves indicate the shape of the curves obtained on plotting the equation $d=k/n$ for different values of k, where d is the "diameter," n the number of crimps per inch, and k is a constant. That is, d varies inversely with the number of crimps per inch or directly with the wave length ($1/n$). The experimental points are very scattered, but they are sufficient to indicate that the general form of the best curve that can be drawn through them is not that of the simple relationship $d=k/n$; that is, there is no direct mathematical relationship between "diameter" or fibre width and the number of crimps per inch. A less steep curve is called for, and we find that the curve to the equation $d^2=k/n$ is about the best curve that can be drawn as a mean through these scattered points. The broken curve satisfies this equation when $k=9\times10^{-6}$. Assuming that the fibre is circular, the cross-sectional area is $\pi d^2/4$. That is, for circular fibres the cross-sectional area is inversely proportional to the square of the diameter, or cross-sectional area $\times$ number of crimps per inch $=k=9\times10^{-6}$. The points lying in the darkly shaded area all satisfy this equation within the experimental error of measurement. It will be seen, however, that only about half the points lie in this area, the others are scattered fairly equally on either side of it.

It is quite improbable that all the fibres measured were circular in cross-section, and although in the case of elliptical fibres this method of "diameter" measurement affords no indication of whether we were measuring the major axis, the minor axis, or (the most probable case) some path across the ellipse intermediate in length between these two, the extreme limits of the magnitude of the serious error involved in assuming d^2 to represent cross-sectional area, where d is the quantity we measured, may be roughly calculated as follows—

The ratio of the minor to the major axis of wool fibre cross-sections has been found to vary from unity to as much as 2·05[5]. Suppose we assume an average circularity ratio of, say, 1·25.* Then if d′ and d″ are the minor and major axes of the ellipse—

$$d''/d'=1{\cdot}25, \text{ or } d''=1{\cdot}25d' \text{ and } d'=0{\cdot}8d''$$

and cross-sectional area = (approx.) $1{\cdot}25d'^2$ or $0{\cdot}8d''^2$.

* This is a normal average value.

Taking the two extreme cases—

(*a*) If the "diameter" measured was the minor axis (d'), then

$$1{\cdot}25d'^2 \times n = 9 \times 10^{-6} \text{ and } d'^2 \times n = 7 \times 10^{-6}.$$

(*b*) If the "diameter" measured was the major axis (d''), then—

$$0{\cdot}8d''^2 \times n = 9 \times 10^{-6} \text{ and } d''^2 \times n = 11 \times 10^{-6}.$$

The experimental error of measurement is the same as before, namely, $\pm 0{\cdot}00005''$, and the area of possible experimental error due to ellipticity plus that due to error in measurement is represented on the diagram by the lightly shaded area. It is interesting to find that almost all the points lie within this area. Ellipticity therefore affords a possible explanation of the cause of the scattered points. The scattering may also be due to other factors which can affect crimp (see later—theoretical considerations).

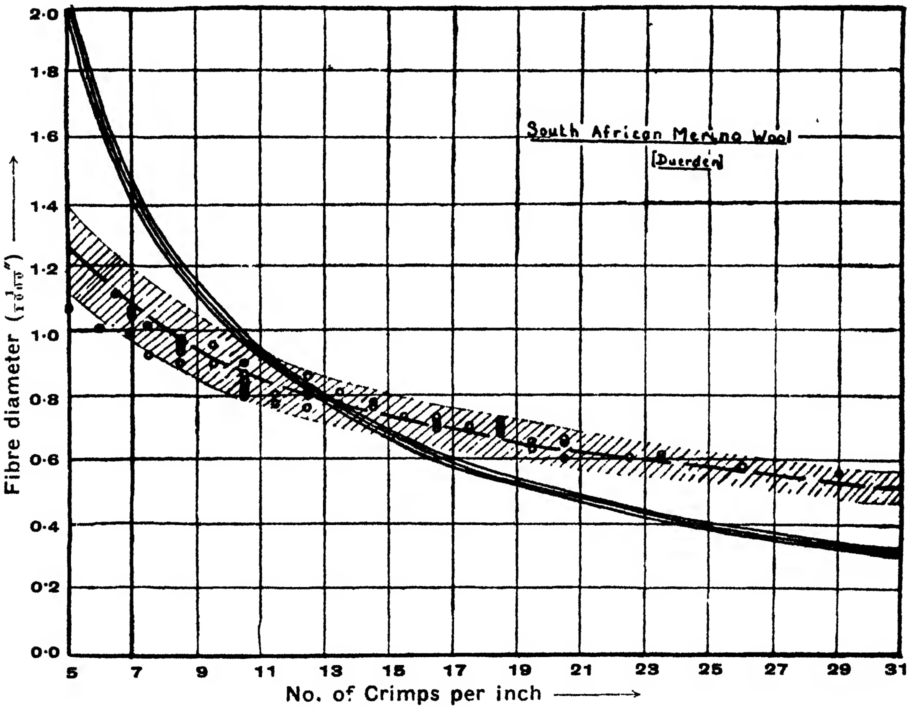

FIG. 3

Fig. 3 is similar to Fig. 2, but is based on the data supplied by Duerden for selected South African wools. The broken line represents the equation $d^2 \times n = k = 8 \times 10^{-6}$. The shaded area again represents the error due to ellipticity, taking the circularity ratio as 1·25, and the three parallel curves indicate the shape of the curves obtained on plotting the equation $d \times n = k$ for three different values of k. The experimental error due to measurement is unknown, and is assumed to be *nil*.

Duerden's data show a more striking approximation to the curve $d^2 \times n = k$ than is shown in Fig. 2, although this closer agreement must be due, at least

in part, to the fact that he rejected some wools as anomalous for his purposes. The cause of the average value of k for these South African wools being slightly lower than the average value ($k=9\times10^{-6}$) for all the wools which are represented in Fig. 2 is not obvious, but it is not without interest in this connection that we ourselves found the greatest deviation from our mean value of k in the case of 66's-70's South African wool, and further, that all the samples giving very low values in this quality number (that is, with cross-section smaller than would be anticipated from the size of the crimp) were 8/9 months wool ex. Port Elizabeth.

Before concluding the experimental section, mention may be made of some experiments made on Russian and Chinese sable fibres. These hairs appear to the naked eye to be perfectly straight and innocent of anything approaching crimp. They were carefully examined in an apparatus which consists essentially of three parts—

(1) A microscope and condenser arranged for projection as used for the optical system of an Einthoven galvanometer.

(2) A rotator for holding a fibre by both ends in chucks, adjustable for distance apart and revolving together, so that the fibre may be viewed radially from any direction.

(3) Arrangements for mounting the optical system and rotator in such a way that the fibre may be moved relative to the microscope in directions parallel and at right angles to its length.

The microscope and condenser are held in a heavy U-shaped casting very accurately machined, so that they are in perfect alignment.* The fibre can be moved parallel with and in the two directions perpendicular to the microscope axis. Illumination is provided by a Pointolite lamp with a 5″ condenser, which focuses the light on the microscope condenser. It has been found convenient to provide the eyepiece of the microscope with a right-angled prism so that the projected map is horizontal. With suitable objectives, magnifications up to $\times 500$ are obtainable.

With such an apparatus it was possible to determine the ellipticity of the fibre at any point along its length. The fibres were fairly stiff, and care was taken to fix them in the apparatus without introducing any twist. The width of each fibre was measured at intervals of 30° during a rotation of 180°. This operation was carried out at each of three points along the length of the fibre, namely, a point about ¼″ from the tip of the fibre, a point in the middle of the length of the fibre, and a point about ¼″ from the root of the fibre. An examination of the typical figures of Table I (due to Mr. R. Burgess, of the Bacteriology Department) shows that the maximum diameter at the tip, middle, and root never occurs at the same angular rotation. Similarly, only one fibre shows the minimum diameter to be at the same angular rotation in these three positions. This clearly indicates that with these fibres the major axis of the elliptical cross-section does not lie in the same plane throughout the length of the fibre. In other words, a slight but definite twist is present which it is permissible to consider to be the first signs of a tendency to curl or crimp, or at least of some periodic variation in the growth of the fibre.

* Made to the design of this Research Association by the Cambridge Instrument Company.

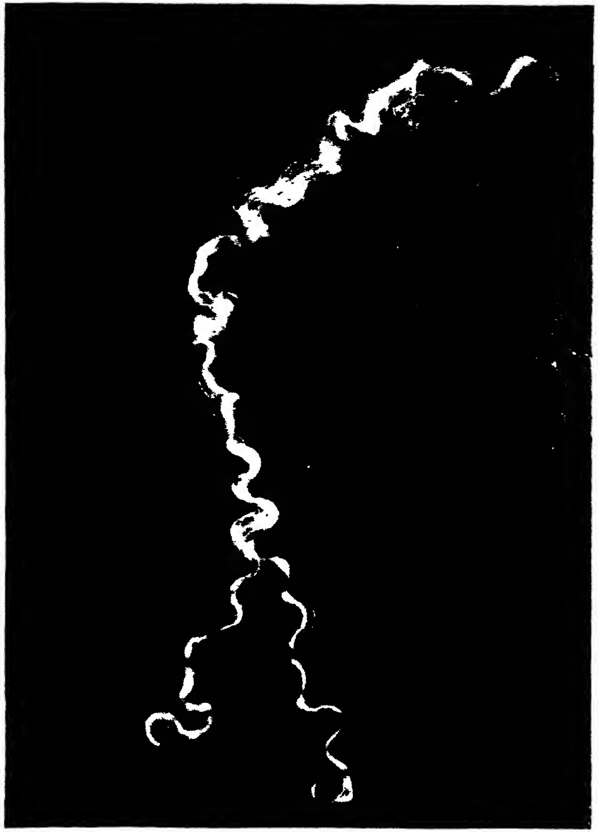

Fig. 1a

Fig. 1b

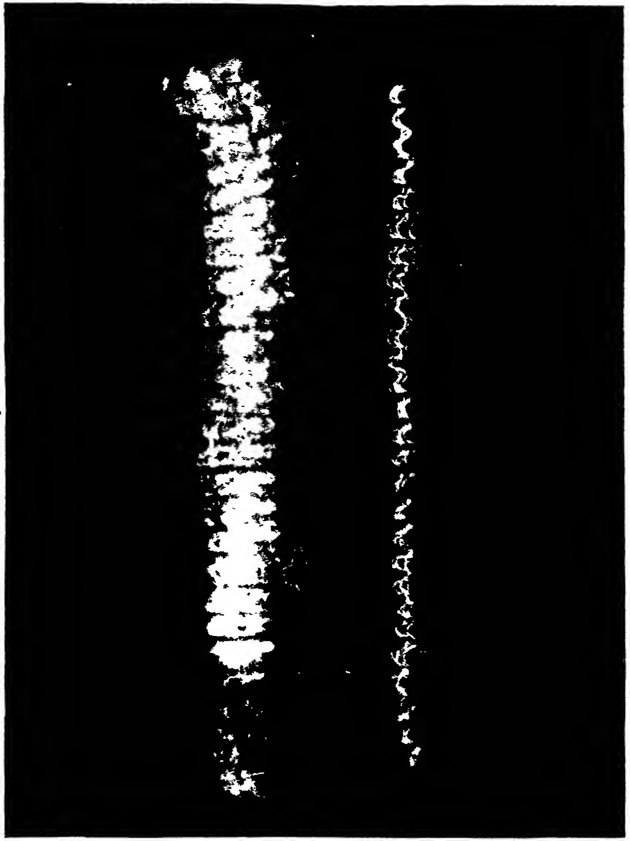

Fig. 1c

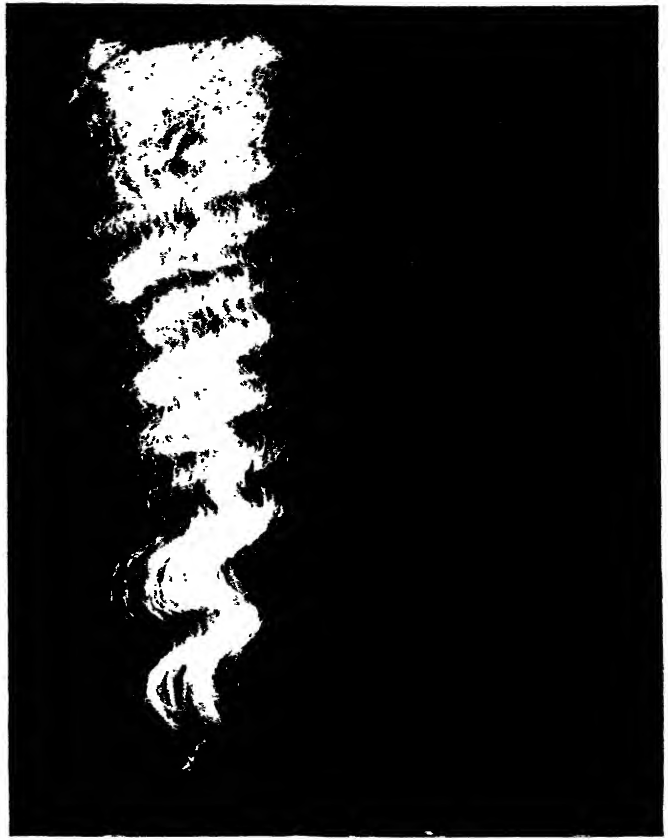

Fig. 1d

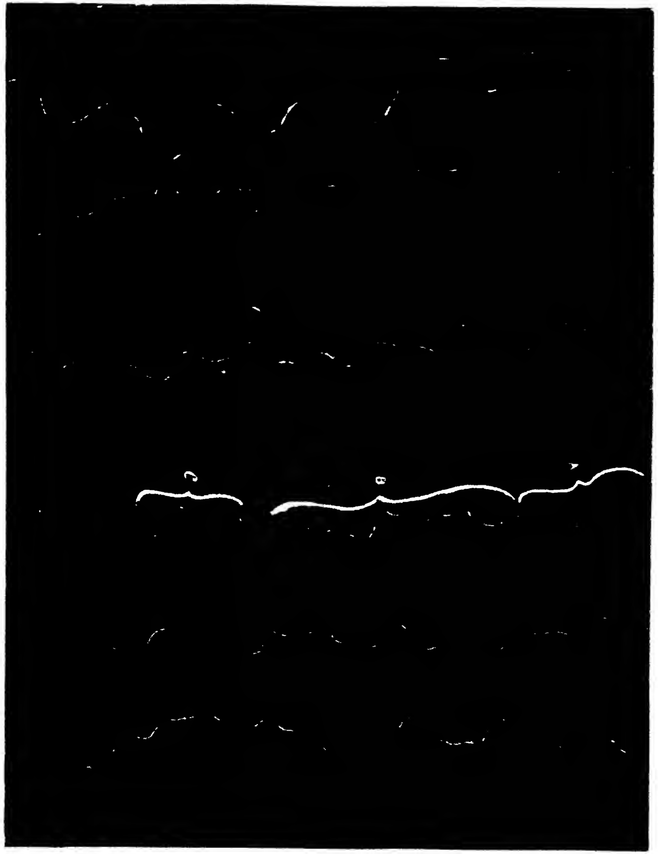

FIG. 1e

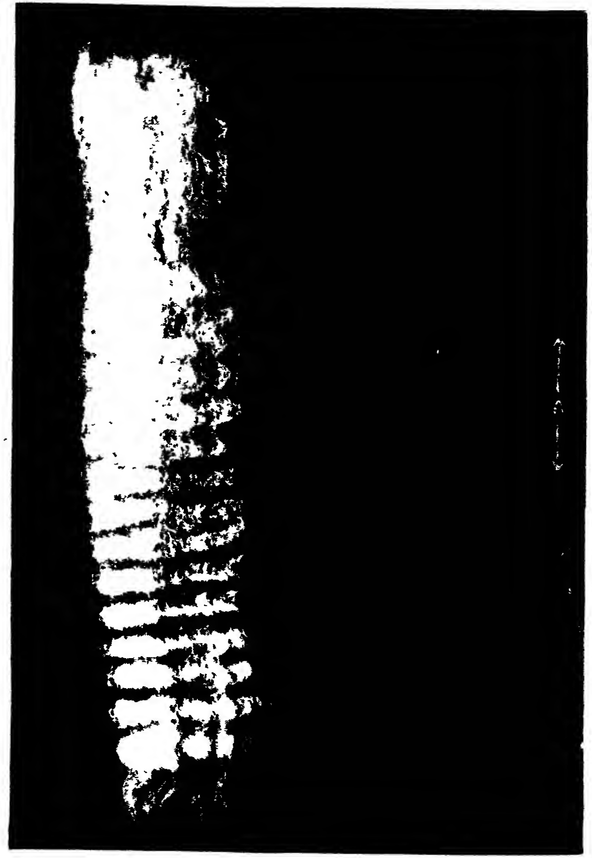

FIG 1f

FIG. 1g

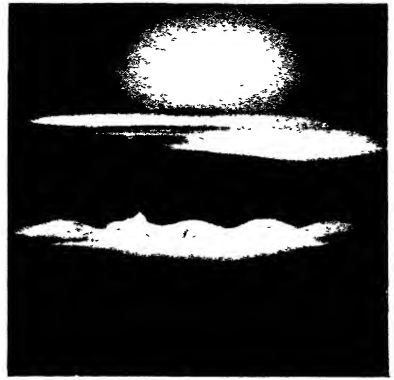

FIG. 5b

FIG. 5a

Table I

Measurements of Fibre Width of Chinese and Russian Sable Fibres at Intervals throughout a Rotation of 180°

Degrees of Rotation	Type of Fibre														
	Chinese Sable												Russian Sable		
		1½"			1⅜"			1¼"			1⅛"				
	*T	M	B	T	M	B	T	M	B	T	M	B	T	M	B
180°	8	9½	7½	6½	5½	4½	8	8½	7	7	7	3½	7½	8	9
150°	9	10	8	7	7	6	8	9½	7½	7	9	5	7	7½	8
120°	8	10½	8	6	8	6½	7½	10	7	7	10	6	7½	9	6½
90°	8	10	7½	5	7½	6½	7	9	6½	8	8½	7	8½	10	6
60°	7	9½	7½	4½	7	6	7	7½	5½	8½	7	6½	9	10	7½
30°	6½	6	7	5	5½	5	7	7	6	7	6	5	8½	9½	9
0°	8	9½	7½	6½	5½	4½	8	8½	7	7	7	3½	8	9	9

* T = tip, M = middle, B = root.

THEORETICAL

The relationship $d^2 \times n = k$ is not without some mathematical justification. In the case of inclined (as opposed to flat) springs, bending as well as torsion comes into play, and twisting is partly dependent on the shape of the cross-section of the spring.

Further, it can be shown that if a continuous filament of length L is bent into the form of a sine curve by a compression force F acting in the direction of its length and causing a bending depression, then assuming the amplitude to be small, a similar expression to that of Euler's formula for the bending of a strut can be derived, namely—

$$L\sqrt{\frac{F}{EI}} = n \quad \text{(1)}$$

where n is the number of waves in the filament, E the modulus of elasticity, and I the "moment of inertia" about a fixed axis.

If I is assumed to be variable, and E constant, the equation becomes—

$$\frac{1}{n} = K\sqrt{I} \quad \text{(where unit length of fibre is considered).}$$

That is, $$\frac{1}{n} = K\sqrt{\frac{\pi a b^3}{4}} \quad \text{for elliptical fibres,}$$

which may be written $\dfrac{1}{n} = K^1 A\sqrt{\dfrac{b}{a}}$ where A is cross-sectional area and a and b the axes of the ellipse.

Thus $n.A\sqrt{\frac{b}{a}} = \textit{constant}$ for elliptical fibres,

and $nd^2 = \textit{constant}$ for circular fibres, i.e. where $\frac{b}{a} = 1$.

It is almost certain, however, that in order to obtain general equations relating size of crimp to cross-sectional area of the fibre with any great degree of accuracy some factor must be introduced which will show the effect of constitutional change as expressed possibly in the variation of elasticity of the fibres. Assuming therefore I to be constant and E variable in equation (1), we have—

$$\frac{1}{n} = K\sqrt{E}$$

or $$n\sqrt{E} = \textit{constant}.$$

That is, the relative wave lengths of the crimp would be dependent on the square root of the modulus of elasticity.

The accurate measurement of the modulus of elasticity of various types of wool has yet to be fully made, but Auerbach[6] has made a few measurements as follows—

Kind of Wool	E Kgs. per sq mm.	T Kgs. per sq. mm
Australian wool—scoured	109	0·074
	131	0·051
German wool—unscoured	86	0·158
	92	0·047

From these few results it is obvious that there is a very definite variation in Young's modulus. That the different constitutional factors of wool do vary with the kind of wool is demonstrated by the results of various workers. Thus sulphur content is known to vary,[7] and Barritt and King have further recently expressed the view[8] that keratinising or hardening of the primary plasmic material into wool cells is brought about by incorporation of sulphur in the form of a cystine nucleus, and that this incorporation takes place to different extents in different types of wool. The analogy is drawn between such a process and the vulcanisation of rubber to various degrees. Duerden[2] mentions the fact that there are different kinds of wool keratin, and, further, that he thinks crimps in wool may be regarded as an index of pliability. Speakman[9], in his work on the plasticity of wool, finds merino wools highly plastic, while English Cotswold wool is much less so.

It is quite probable that further considerations and experiments along such lines as indicated above would lead to the discovery of some relationship, having a chemical and physical basis, between crimpiness and the spinning properties of wools. In any case the above method of treatment indicates that elasticity plays a prominent part in the determination of wool quality, and that in the determination of the relationship between spinning power and quality two factors have to be considered, namely, the purely dimensional, as indicated by the introduction of the factor I above, and the constitutional or structural, as evinced by the presence of the modulus of elasticity, E, in the expression derived.

The divergence of our results from the mean value of $k=9\times10^{-6}$ referred to above may quite possibly be partly due to some difference in elasticity

of the different kinds of wools employed, and the fact that the South African wools approximate fairly close to the mean value of $k=8\times10^{-6}$ may be partly explained by the fact that all these wools were from merino sheep kept under similar conditions, the wool of which would therefore most probably be of fairly constant elasticity.

SECTION II—A PHYSICAL EXPLANATION OF THE PHENOMENA OF CRIMP AND CURL

It was pointed out in Section I that all types of curl and crimp are found in wool samples, varying from a simple spiral to uniplanar crimp waves. In every form all portions of the fibre in its unstrained state lie within a short distance of the axis of that form.

(1) When the fibre assumes a helical formation we get an approximation to the form obtaining in a spiral spring where the axis of the spring is inclined at a finite angle to the horizontal. A not infrequent occurrence in this type of curl is a reversal in the direction of rotation of the spiral, a right-handed spiral may become left-handed and vice-versa.

(2) When the waviness lies in a single plane, thus—

the plane may remain constant throughout the length of the fibre or may be found to twist, so that when a fibre is placed on a flat surface the plane of part of the crimp will be in the same plane as that surface and part will be in a plane or planes inclined at an angle to the plane of that surface.

In order to represent any of these forms of crimp mathematically or actually reproduce them with a mechanical model, it is necessary to combine two simple harmonic motions working at right angles.

A simple mechanical model for the production of crimped filaments, which we have designed, and with which we have been able to reproduce many of the geometric forms found in wool fibres, has been assembled as follows. Two small wheels of equal size are made to rotate horizontally at equal rates by means of a large common cogwheel driven by a gramophone motor. Both small wheels are drilled by holes at equal distances stretching across two diameters at right angles to each other. The wheels are so arranged that during rotation each of the rows of holes on one wheel remains parallel to each of the rows of holes on the other, respectively. Two flat metal rods are joined at one end by a hollow pivot. Each of the two free ends is fitted with a small upright peg, by means of which this end of the rod can be fixed to one of the small wheels by pegging into any one of the holes of that wheel. The length of the rods and the distance of the wheels is so arranged that when the free ends of the rods are pegged one each into the centres of the small wheels, the angle formed at the pivot is 90°, and on rotation of the wheels the position of the pivot remains constant. Again, when the free ends of the two rods are fixed at equal parallel distances from the centres of the two wheels, on rotation the pivot describes a circle. It will readily be seen that by varying the positions of the free ends of the rods in the wheels a very large range of possibilities presents itself, and the pivot can be made to move in many paths, including a series of straight lines inclined at all angles to each other, ellipses of different size and shape and circles of various radii. A small glass tube, drawn out to form a capillary

jet, is connected by high pressure rubber tubing to an ebonite pump filled with some viscous solution that will solidify rapidly on contact with some medium which coagulates it (e.g. a solution of viscose coagulated by an aqueous solution of sulphuric acid and sodium sulphate.) The viscous solution is squirted gently through the capillary jet, while the pivot is made to move in the path desired. By this means it is easy to obtain viscose fibres which show all the types of crimp and curl found in natural wool fibres.

Any form of mechanical model which would combine the effects of two simple harmonic motions acting at right angles would suffice. A device which will produce fibres for artificial textiles showing uniplanar crimp has been devised by Speakman[10]. Alternatively, it might be possible to use a vibrating point maintained in vibration by electromagnetic means. The figures such models can produce are well known to physicists under the name of Lissajou's figures, and are very similar to those produced by the projection of the various forms of curl and crimp found in wool on to a plane perpendicular to the axis of that form.

The following mathematical study is a preliminary contribution to a geometric study of the fibre form—

Denoting by z the distance of an element of the fibre from, say, the skin, and x and y the perpendicular co-ordinates of the element in a plane perpendicular to the fibre, the most general form of a fibre can be represented by the equations—

$$x=a\theta$$
$$y=b\varphi$$
$$z=ct$$

where θ and φ are oscillatory functions of t, an independent variable, which is intimately related to, or which may be, the time of growth of the fibre; a, b, and c may be regarded as constants over relatively short periods of t, although all of them are probably functions of t also over long periods.

The simplest oscillatory function of t is the sine function, and we shall assume for the detailed consideration of the problem that the equations

$$x=a \sin \omega t$$
$$y=b \sin (\omega t+\alpha)$$
$$z=ct$$

represent the simple forms of the fibre, each of these simple forms corresponding to appropriate values of a, b, c, and α.

For example, if a, b, or α be zero, the form of the fibre so represented will exhibit uniplanar crimp of definite amplitude and wave length. Alteration in the number of crimps per unit length may then be due to a change in the value of ω or of c.

Further, if α remains zero, while a and/or b vary, the plane of bending will alter. It is possible, for example, to account for a rotation of the plane of bending while the amplitude remains constant by simultaneous variation of a and b, so that the sum of their squares remains constant. The adjoined table shows how the values of a and b vary, so that the sum of their squares is equal to 100, and the table gives the corresponding rotation of the plane of bending.

θ ...	0°	5·7°	11·5°	17·5°	23·6°	30°	36·9°	44·4°	53·1°	64·2°	90°
b ...	0	1	2	3	4	5	6	7	8	9	10
a ...	10	9·95	9·80	9·54	9·16	8·66	8	7·14	6	4·36	0

This type of change of form has been observed in many cases (see Fig. 1e).

Again, if a and b remain constant, while α varies, say increases from zero, the uniplanar wave form will change first to a curl, formed as it were on a flat elliptical cylinder until, when α becomes $\frac{\pi}{2}$, the cross-section of the moulding cylinder would be an ellipse of axes $2a$ and $2b$.

In the particular case when $a=b$, and when $\alpha = +\frac{\pi}{2}$, the fibre would take the form of a helix of definite radius and pitch, while if the value of α changed to $-\frac{\pi}{2}$, the form would still be a helix of the same radius and pitch, but whereas the first would correspond to a right-handed screw the second would be left-handed.

Two such forms in the same fibre have been observed, and in view of the special interest attached to such an effect, the geometrical theory will be considered in detail.

The right-handed screw of radius a and pitch p is represented by the equations—

$$x=a \sin \omega t$$
$$y=a \sin \left(\omega t+\frac{\pi}{2}\right)=a \cos \omega t$$
$$z=\frac{\omega}{2\pi} pt$$

and the corresponding left-handed screw by the equations—

$$x=a \sin \omega t$$
$$y=a \sin \left(\omega t-\frac{\pi}{2}\right)=\text{a} \cos (\omega t-\pi)$$
$$z=\frac{\omega}{2\pi} pt$$

The change from the one screw to the other is usually slow, corresponding to a change of about $\frac{2\pi}{\omega}$ in the value of t.

Taking as our zero of t the value corresponding to the onset of the change, the form of the fibre over the change will be represented by—

$$x=\text{a} \sin \omega t$$
$$y=\text{a} \cos (\omega t-\theta)$$
$$z=\frac{\omega}{2\pi} pt$$

where θ is the total lag of the y component on the x component introduced during the interval o—t.

Let us now suppose that the lag θ is proportional to t, and that the total lag π occurs in time $\frac{2\pi}{\omega}$. We then have the following equations to represent the form of the fibre during the change—

$$x=\text{a} \sin \omega t$$
$$y=\text{a} \cos \frac{\omega}{2} t$$

the equation for z being dropped, because in observations of the form of the

fibres x and y components are of greatest interest. The projection of this form on the x—y plane is given in Fig. 4, case I.

It appears, however, that our assumptions are equivalent to the assumption that there are sudden changes in the period of the y component. As it will obviously be difficult to assign any cause to such an effect, we proceed to consider an alternative suggestion.

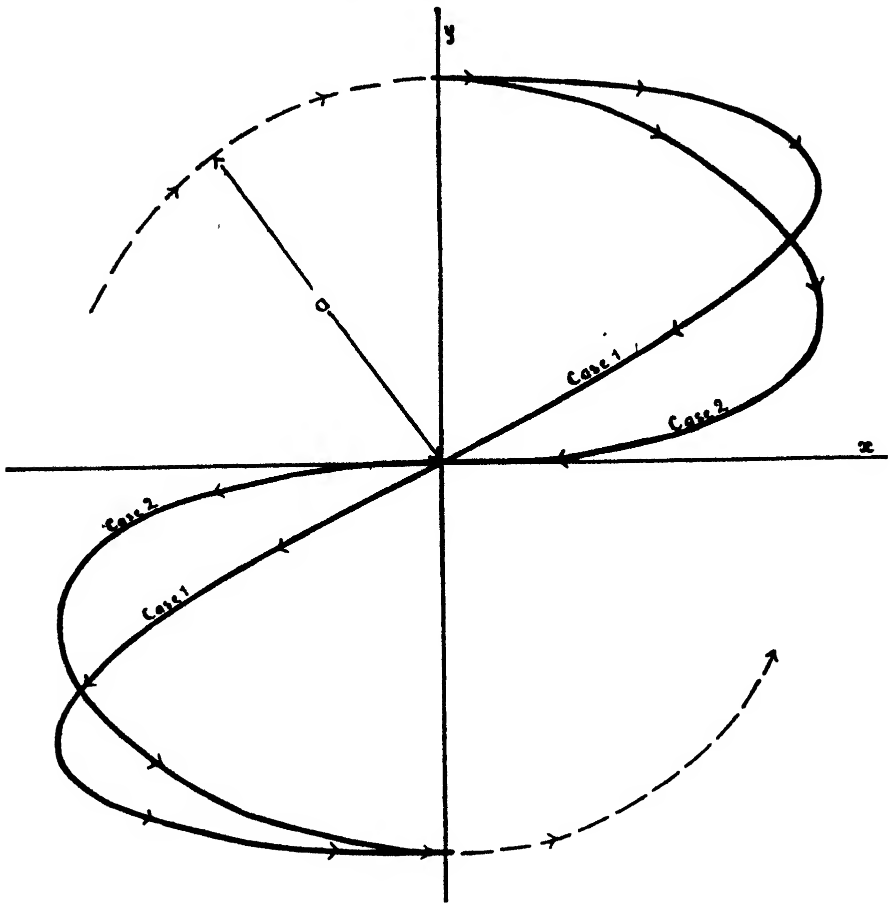

Fig. 4

We shall now suppose that the phase retardation is due to a continuous uniform change in the period of the y component from its normal value to a new value and back to the normal value. This assumption involves no such discontinuity as that mentioned above.

We now write the equations for the fibre during the change of form—

$$x = a \sin \omega t$$
$$y = a \cos \varphi$$

in which $\dfrac{\delta\varphi}{\delta t} = \omega\,(1 - kt)$, so that

$$\varphi = \int_0^t \frac{\delta\varphi}{\delta t}\,dt = \omega t(1 - \tfrac{1}{2}kt),$$

these equations to apply until $\dfrac{\delta\varphi}{\delta t}$ reaches its minimum value.

If this minimum value be reached when $t=\frac{\pi}{\omega}$, and if at this time the lag introduced be $\frac{\pi}{2}$, we have—

$$k=\frac{\omega}{\pi}$$

so that our equations become—

$$x=a \sin \omega t$$

$$y=a \cos \omega t \left(1-\frac{\omega}{2\pi}t\right)$$

If now we take $\frac{2\pi}{\omega}$ as a new unit of time, so that the new time is given by—

$$\tau=\frac{t}{\frac{2\pi}{\omega}}$$

the equations assume the more manageable forms—

$$x=a \sin 2\pi\tau$$

$$y=a \cos 2\pi\tau(1-\tau)$$

and, for the next half period during which the period of the y component returns to its normal value, we have—

$$x=a \sin 2\pi\tau$$

$$y=a \cos \{(\pi-2\pi\tau(1-\tau)\}.$$

Fig. 4, case 2, shows the form of the fibre during such a change. Several fibres have been observed which show an appearance similar to this (see Fig. 1b).

It appears that appropriate modification of the characteristic equations would bring practically all fibres within this simple scheme, and it remains now to locate the cause of these effects.

Whether any such state of affairs as we have assumed above actually exists at the follicle has not been demonstrated, but there is certainly evidence in the field of biological observation that periodicity or rhythm is not an unusual feature in the growth of hair. Thus the hair of insectivores and rodents, and also of some other forms, is characterised by a discontinuous medulla. Hollow spaces alternate regularly with bridges of solid material. There is a type of pigment distribution in these hairs that is no less strikingly periodic. Granules may be seen at the proximal portion of each air-space. In an albino rabbit the granules are colourless, but if the hair is grey, these granules are black. Alternating bands of different colours are often seen in hairs, and it is noteworthy that the transition from one colour to the next is sharp and definite. Another type of periodicity was observed in the American opossum[11] (Coenolestes), in which hairs showed a regular alternation of portions with and without medulla.

In the growth of feathers in birds far more striking rhythms are to be found. Apart from such alternations in colour as is shown in the barring of breeds of fowls such as the Plymouth Rock, there is the case of the ostrich feather, in which it has been demonstrated that alternating bands reflect the difference between day and night temperatures.

Hair follicles are able to produce fibres that show an immense range of differences in structure along their length. For example, the protective outer hairs of the rabbit have a swollen distal portion that is many times the diameter of the finer proximal portion. A somewhat similar though less

striking condition is seen in the heterotype fibre in the sheep[12]. There is also considerable evidence that the same hair follicle may at different times produce hairs that are of totally distinct types.[13]

Neither is it necessary for us to confine ourselves to the field of biological science in searching for examples of periodicity exhibited during an otherwise continuous process. A wealth of examples can be found described in the literature of physical chemical processes (see, for example, Copisarow, *Kolloid Zeit.*, 1929, **47**, 60-65). Hedges and Myers, in their little book, "Physico-Chemical Periodicity" (Arnold, 1926), have given an excellent survey of the subject, and they append a full bibliography. In the closing paragraph of the book they say—

"Periodicity as a feature of the processes and functions of living organisms is so apparent that enumeration of examples seems unnecessary, but consideration of the heart-beat indicates that it is a feature of fundamental importance. It is not impossible that the same property is at work in these cases, for living organisms are made for the most part of colloidal matter. It may be that a periodic stimulus is caused by a progressive increase in concentration of some substance at an active surface in the organism. This is a matter for the future; for the present it is sufficient to show that periodicity is a feature of purely physical as well as biological systems."

It would appear therefore that the phenomena of crimp need not necessarily depend on some fundamentally biological property, but that an explanation on purely physical grounds would be quite feasible. At the suggestion of Dr. Hedges, experiments were performed in our laboratories on the formation of crimped fibres from purely colloidal "growths." Such a formation is shown in Fig. 5. The experimental method was as follows. A capillary tube was filled with a colloidal solution of arsenious sulphide (approx. 0·25%), sealed at one end and then introduced into a test tube containing a 10% solution of ferric chloride. The test tube was tightly corked and allowed to remain in a horizontal position undisturbed for about 48 hours. The result was that a well-formed filament appeared in the capillary having a distinct periodic structure of a crimped character. The photograph in Fig. 5a shows the filament inside the tube, and Fig. 5b is an enlarged image obtained by photographing the same filament under higher magnification. This filament shows the characteristics of uniplanar crimp. It is thus demonstrated that crimp could possibly be formed as a characteristic of the mode of formation of the fibre substance itself without reference to any mechanical action at the follicle.

SUMMARY OF RESULTS

It has been shown that the crimp or waviness in wool fibres can be accounted for by hypothesising two periodic or simple harmonic forces acting at right angles at the follicle in addition to the force exerted to promote extrusion and growth. By change of phase difference between the two periodic forces, each and every kind of crimp can be reproduced, and this is actually carried out by means of a mechanical model. With regard to the relationship between the number of crimps per inch and the fibre thickness it is shown that there is a relationship of the form—

$k=nd^2$ . . . for circular fibres, where d is the diameter, and

$k=nA\sqrt{\frac{b}{a}}$ . . . where A is the area of an elliptical cross-section, n the number of crimps per inch, and k is a constant.

The value of k has been shown to be in general about 9×10^{-6}, but in the case of South African wools the value approximated more closely to 8×10^{-6}. It is thus obvious that in fibre analysis and any possible relationship of fibre thickness to wool quality, the area of cross-section is the quantity to be measured and not the so-called diameter. In the case of circular fibres the relationship between crimp and fibre thickness can be expressed as "the square of the diameter is inversely proportional to the number of crimps inch."

It is not to be concluded that the foregoing suggestions are other than a physical explanation of the phenomenon. The results are put forward as the basis of future biological observation which may interpret correctly how the physical forces outlined above can exist in the follicle, and also find to what degree the physical interpretation can be borne out by biological fact. It has been suggested that the growth of the wool fibre is intermittent from side to side. The exact nature of the forces to create such periodic growth are unknown, and hence the present paper presents a field for observation by the biologist.

In conclusion, the authors' thanks are due to Mr. N. Tunstall, of the Physics Department, for his assistance; to Mr. A. J. Fraser Roberts, of the Biology Department; to Professor J. E. Duerden, of South Africa, for so generously placing the results of hundreds of his observations at our disposal; to various members of the Association for their interest in providing suitable samples for analysis; and to Mr. J. Amos, foreman of the Association's workshops, for his work in the manufacture of the mechanical model for the reproduction of crimp.

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2—THE GRATING PERIODOGRAPH FOR THE ANALYSIS OF SERIES OF OBSERVATIONS FOR HIDDEN PERIODICITIES

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I—INTRODUCTION—THE PERIODOGRAM

One of the earliest papers from the Shirley Institute[5] described a photographic method for assessing the regularity of cotton yarns, reproduced typical traces obtained by means of the apparatus, and also included a number of plotted records of tensile strengths or twists measured at short intervals along continuous stretches of yarn. The production of similar records, with improved appliances, has become the routine practice in all subsequent researches in spinning when it has been desired to judge the regularity of the product. It has long since become necessary, however, to devise a method by which the accumulations of data or the plotted or photographic traces could be examined for hidden periodicities. The grating periodograph now described is an instrument which has been developed for the purpose. Although designed for the examination of the irregularities in cotton spinning products, it can of course be applied to the analysis of any series of observations in which the existence of periodicities is suspected.

The periodograph is simply a method of carrying out automatically the periodogram analysis[2,6] of series of observations for hidden periodicities. It also allows Schuster's method of secondary analysis to be performed in a very convenient manner.

In order that the action of the instrument may be more readily understood, the periodogram method will first of all be briefly outlined. It consists essentially in testing the series of observations (which might be, for example, in researches on spinning, a series of measurements of the height of the curve obtained by means of the photographic regularity tester) for a large number of trial periods covering a wide range. Let the observations, which are supposed to be taken at equal intervals, be u_0, u_1, u_2, etc.; then in order to test for a period of length q intervals, the mean of u_0, u_q, u_{2q}, etc., is calculated, and then the mean of u_1, u_{q+1}, u_{2q+1}, etc., and so on up to the mean of u_{q-1}, u_{2q-1}, etc. If a number of periods of length q are thus averaged, the amplitudes of periodicities of lengths other than q or sub-multiples of q and the random variations are considerably reduced, so that only when a periodicity of length q or some sub-multiple of q is present in the observations do the means of the values of u differ considerably from one another. Hence, if this calculation is performed for trial periods of various lengths, those which yield the maximum amplitudes give the lengths of the most probable periodicities.

It is still necessary, however, to separate the period q from its sub-multiples, and in the second part of the periodogram method the means of the u's are analysed harmonically, so as to give the amplitude of the period

q independently of those of its harmonics. If $U_0, U_1 \ldots U_{q-1}$ are these means, then the amplitude, R, is given by

$$R^2 = A^2 + B^2$$

where A and B are calculated from the U's by the formulæ

$$A = \frac{2}{q} \sum_{r=0}^{r=q-1} U_r \cdot \cos 2\pi r/q$$

$$\text{and } B = \frac{2}{q} \sum_{r=0}^{r=q-1} U_r \cdot \sin 2\pi r/q$$

If several series of observations have to be examined, the labour involved in the periodogram analysis is prohibitive, and it is practically essential to have some mechanical means of performing the most laborious part of the work. Instruments which enable the first part of the analysis to be rapidly carried out have been devised by Douglass[4] and Balls[1]. The new instrument described here owes the method of presenting the observations for analysis to that of Douglass, but it performs the addition of equally spaced observations in a much simpler way and, by a slight modification, allows a given period to be separated from its harmonics as in the second part of the periodogram analysis. This has proved an almost essential advantage in examinations of the variations in cotton spinning products carried out in these laboratories. If required, the apparatus can also easily be adapted to allow a spectrum of the periods to be photographed.

The remaining sections of this paper explain the principle of the automatic method and give sufficient practical details to enable other workers to set up and use the apparatus. Since, however, the method differs slightly in detail from the periodogram, and this difference may lead to effects which are at first rather puzzling, one section is devoted to the mathematical theory of the instrument, and the results of this which are of use in practice are collected together in a more convenient form at the end of Section III.

II—PRINCIPLE OF THE METHOD

The observations to be analysed are plotted and the area under the curve is made white on a black background, as shown in Fig. 1. The curve is set up parallel to a grating consisting of a series of parallel equidistant slits, the slits being perpendicular to the length of the curve (Fig. 2). Behind and parallel to the grating is a ground glass screen.

Assuming for the time being that the slits are infinitely narrow, then, if the curve is uniformly illuminated and its ordinates are small in comparison with its distance from the ground glass, the illumination at a point B on the screen through the slit D_1 is proportional to the ordinate of the curve at T_1, that through the slit D_2 to the ordinate at T_2, and so on. The total illumination at B is therefore proportional to the sum of a number of equidistant ordinates of the curve. The spacing, q, of these ordinates is given by—

$$\frac{T_1T_2}{D_1D_2} = \frac{T_2T_3}{D_2D_3} = \frac{v+u}{v}$$

$$\text{i.e. } q = \left(1 + \frac{u}{v}\right) s, \qquad (1)$$

where s is the spacing of the grating, u is the distance of the curve from the grating, and v the distance of the screen from the grating. As the point B moves across the screen the system of ordinates moves along the curve, and the variation of the illumination gives the result of the first part of the periodogram analysis. If q is equal to p, the length of one of the periods in the curve, the screen is crossed by a number of light and dark fringes, but for other values of q the illumination is nearly uniform or the fringes are faint. Their formation may perhaps be understood more clearly in another way; if a period of length T_1T_2 is present (Fig. 2), and the maxima are at $T_1T_2T_3$, then there is a bright band at B, whereas at a neighbouring point C, which receives light from the intermediate portions of the curve, the illumination is less, while at B^1 it is again a maximum.

The periodicities can thus be detected and measured by observing the positions of the grating and screen which make the visibility of the fringes a maximum and calculating the length of the period from equation (1).

In practice the width of the grating slits cannot be infinitely small, but must be finite, so that the illumination at a point on the screen due to one slit is proportional to the mean ordinate of a short length of the curve. This makes no essential difference and is rather an advantage than otherwise, as it is equivalent to smoothing the curve.

It is interesting to calculate completely the amplitude of the fringes due to a simple periodic curve. If the curve is assumed to be of infinite length, the calculation will be found to be mathematically identical with that for the amplitude at a point in the spectrum of a monochromatic beam of light produced by a plane diffraction grating; q in equation (1) corresponds to the path difference between the beams diffracted by adjacent lines of the grating and the averaging of short lengths of the curve by the wide slits to the diffraction by a single line. Just as the lines in a spectrum are of finite width and are flanked on either side by faint companions, so, as the ratio of u to v on the periodograph is changed, the visibility of the fringes passes through a series of faint secondary maxima as q approaches p, falls to zero and then finally rises comparatively gradually to a strong principal maximum when q becomes equal to p. With the actual fairly irregular curves the secondary maxima are so faint and confused that they are rarely distinctly observed.

The close analogy between the periodogram and the diffraction grating has, of course, already been pointed out by Schuster. It has also been briefly explained here because the analogy is even closer with the periodograph and because the fringe pattern produced by a simple periodic curve forms an interesting diagrammatic picture of the light vibrations in a spectrum. The whole pattern produced by the simple periodic curve may be made visible at once by inclining the ground glass screen to the grating as indicated in Fig. 3. The screen then cuts through the planes corresponding to different values of q and the system of fringes appears as a series of apparently corrugated bands. Fig. 4 was prepared by replacing the inclined screen by a photographic plate. The strong principal band and several of the faint secondary bands and their phase differences can be clearly seen.

With a curve containing several periodicities an inclined screen gives a kind of spectrum of the periods; for each period produces a band of fringes across the screen in a position corresponding to its length. If a permanent record is required the spectrum can easily be photographed by the use of a

plate instead of the ground glass. Fig. 5 was prepared in this way and shows some of the periods for a drawframe sliver drafted under certain abnormal conditions, immaterial to the present description. The necessary formula for calculating the lengths of the periods from the positions of the bands on the plate is easily deduced and the plate can be calibrated by the use of two periods of known lengths.

Even when a record is not required, the use of an inclined screen is a great advantage, for it is then only necessary to move the grating until the band of fringes is bisected by a line ruled across the screen. This adjustment is much less strain on the eyes and probably more accurate than that for maximum visibility on a vertical screen.

So far it has been assumed that a period of length p produces only one principal band of fringes. However, just as in the first part of the periodogram analysis, periods whose lengths are sub-multiples of p also produce fringes for the same setting of the grating and screen, in other words, each period gives fringes of the first, second, third, etc., orders.

When the curve is only to be explored over a limited range of periods, or when only one or two periodicities are present, the higher order fringes cause very little trouble; for they can be distinguished from the first order by their smaller width and, even when there is still some doubt, the different orders can be separated by harmonic analysis of the original data. But if there are several periodicities in the curve, the work involved in the harmonic analysis, though still only a fraction of what would be required for the calculation of a complete periodogram, is considerable and it is a great advantage so to reduce the amplitudes of the higher orders that they are practically invisible and each period produces only one prominent set of fringes.

The amplitudes of the higher order fringes are determined by the relative widths of the clear and opaque portions of the grating. Thus, when these are equal, all the even orders are absent, which provides a method of extending the range of the instrument and suggests that by employing a certain form of grating all the higher orders might be eliminated. The second part of the periodogram analysis shows that this may be achieved by using a harmonic grating, i.e a grating for which the light transmitted at a point distant x from the edge is proportional to $(1 + a \cos 2\pi x/s)$. A photographic method of making approximately harmonic gratings, which cut down the visibility of the higher order fringes so much that they can be ignored, is described in the last section of the paper. By their use the periodograph practically performs the complete periodogram analysis of the curve, except, of course, that the amplitudes of the periodicities can only be estimated from the appearance of the fringes, and if numerical values are required they must be calculated from the original data.

For the complete periodogram analysis, as described above, to include the whole of the curve, it is obviously necessary that the width ($2d$) of the grating should be greater than $2l \div (1 + u/v)$ where $2l$ is the length of the curve. When the grating is narrow, the analysis only extends over a length $2d(1+u/v)$ of the curve. For a point (R, Fig. 2) in the middle of the screen this length is in the middle of the curve, but for a point one fringe width to the left, the corresponding portion of the curve is one period to the right of the mid-point. By screening the sides of the grating and measuring the positions of the fringes the mean phase of the period in successive overlapping portions of the

curve can therefore be determined. This corresponds to Schuster's method of secondary analysis, but it does not give the period any more accurately than the ordinary method, which, unlike the periodogram, allows the length of the trial period to be varied continuously. It is, however, useful in searching for and measuring possible changes of phase in the periodicity.

III—PRACTICAL DETAILS

Description of the Instrument

The most convenient way of using the periodograph is to keep the screen at a fixed distance from the curve and vary the length of the trial period by moving the grating. This arrangement is also necessary for other reasons, for if the screen is too close to the curve, more weight is given to the middle of the curve on account of the obliquity and greater path of the rays from its ends and on account of the incomplete diffusion of the light by the ground glass. The effect of both these causes is minimised by making the distance between the screen and the curve as great as is convenient and keeping it constant. The error due to incomplete diffusion is also reduced if the eyes are held a little above the middle of the screen so as to avoid directly transmitted light, and may be made very small by using the method of secondary analysis. If the curve is 20 cms. long and is kept about 50 cms. from the screen, the error is not serious provided that well ground glass, such as that used for camera focussing screens, is employed.

The following practical details of the instrument which was used in the work on spinning mentioned above will probably be useful.

The observations to be analysed are plotted on a fairly large scale and the area under the curve is blackened. In doing this it is advisable to cut off any very low minima (see Fig. 1) as this greatly increases the visibility of the fringes without affecting the lengths of the periods. The curve is then photographed on a process plate $8\frac{1}{2} \times 2\frac{1}{8}$ inches, a size which can be obtained from the manufacturer ready cut. For a rapid examination the curve may be drawn on thin paper and used directly. The paper curve or the negative is supported in a vertical plane with its length horizontal in a suitable holder opposite a rectangular hole in a wooden lamp house, L, Fig. 3, which is painted inside with a matt white paint and contains four 60-watt lamps arranged so that no direct light can reach the screen. The lamp house is clamped at one end of an optical bench, B, and at the other end is fixed the ground glass screen, S, inclined at 45° to the vertical. The grating is fixed vertically to a sliding stand by means of a holder, H, which allows it to be replaced by another in the same position and which is wide enough to prevent light from the ends of the curve from reaching the screen past its sides.

Two harmonic gratings, 10 × 15 cms., of spacings about 0·75 and 4 mm., and containing 200 and 37 lines respectively, cover a range of periods from 1 to 40 mm., but for convenience one of intermediate spacing (1·5 mm.) is also used, as the fringes produced by the fine grating are a little difficult to observe.

Calibration

There are two constants to be determined—the distance of the screen from the curve and the scale correction for the grating. These are best found by calibration against two periods of known lengths. A series of

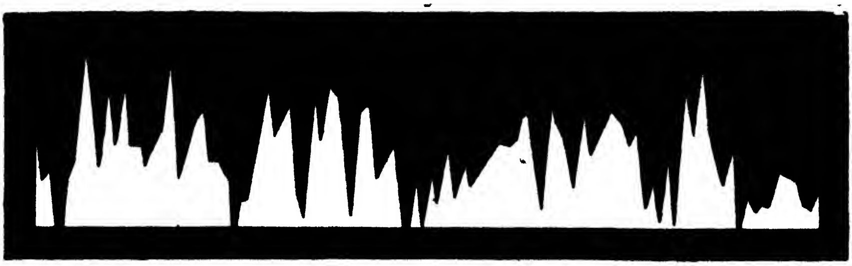

Fig. 1

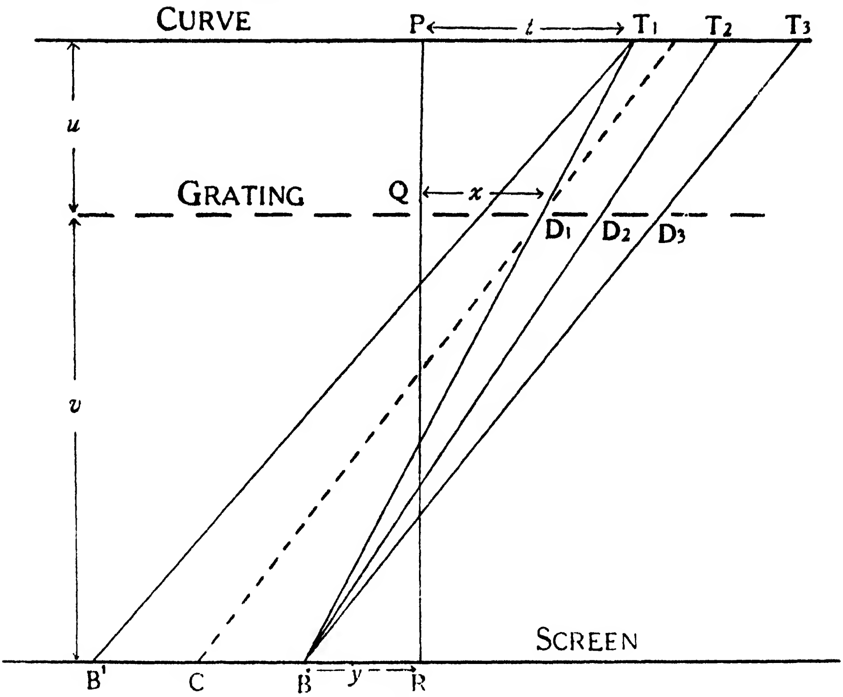

Fig. 2

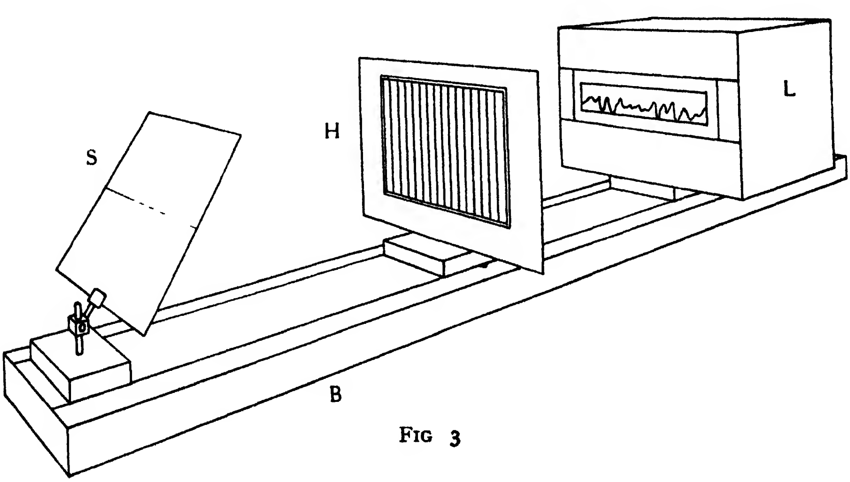

Fig 3

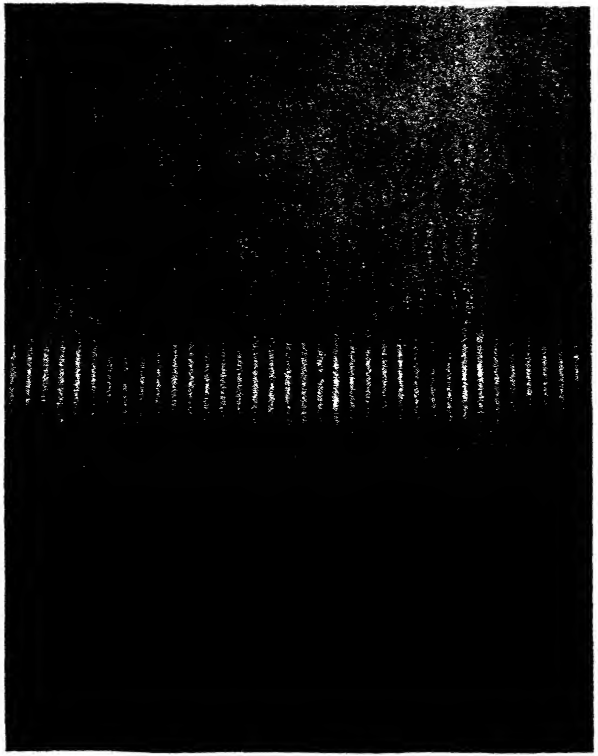

Fig. 4

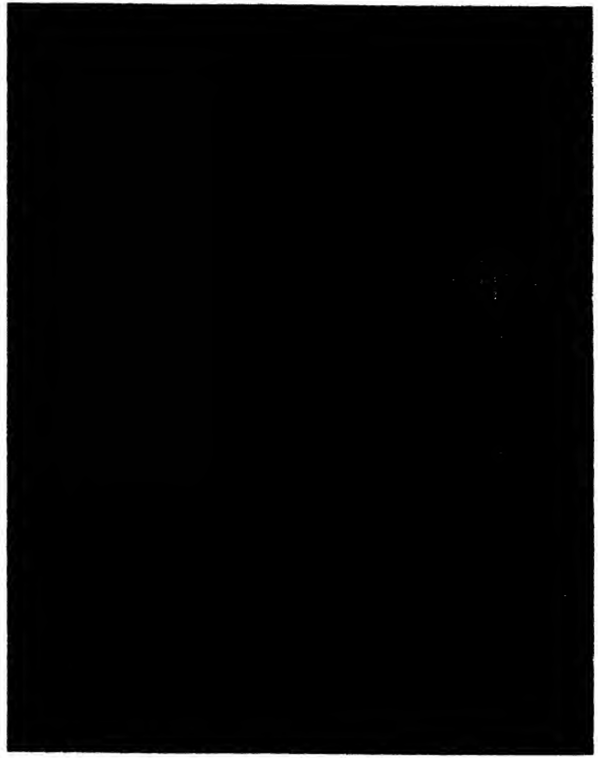

Fig. 5

parallel dark lines on a clear ground is suitable, the fundamental and one of the harmonics providing the two known periods.

Use of the Instrument

In using the periodograph it must be remembered that the length of the curve is constant, whereas when a series of observations are analysed by the periodogram only so many of them are taken as will give an exact whole number of trial periods. This difference is important, for it causes the introduction of other groups of fringes, which, although they are usually so weak that they can be ignored, may at times be misleading. For this reason the theory of the periodograph has been completely worked out and is outlined in the next section. Two of the additional groups of fringes are always negligible—at least they have not so far been observed—and with a harmonic grating the third group is usually very faint when there are more than eight complete trial periods in the length of the curve. If the lines of the grating are regarded as acting like a series of pinhole cameras, these fringes are seen to be due to overlapping images of the curve on the screen, and they are produced when the curve is replaced by a rectangular slit of the same length; in fact, once their behaviour has been carefully studied by using such a slit, there is little danger of mistaking them for the principal set of fringes. They can be avoided by screening the ends of the curve so that it contains a whole number of trial periods, or by screening the grating until it is a little too narrow to include the whole of the curve (see Section II); the fringes are then absent from the central region of the ground glass. When doing this it is best to use a vertical screen.

There are one or two other results of the theory which are often required in practice. As applied to the periodogram they are well known, but for convenience of reference they are collected together below in a form suitable for direct application to the present method.

Depth of the Principal Band of Fringes—The limits of the principal band of fringes corresponding to a period p are defined by the values of u and v satisfying the equation—

$$\frac{v}{u+v} = s\left(\frac{1}{p} \pm \frac{1}{2l}\right) \tag{2}$$

where $2l$ is the length of the curve (see p. T25). Therefore, if v_1 and v_2 define the positions of the grating which bring the two minima on either side of the principal maximum on to the ground glass and $h = u + v =$ constant.

$$v_1 - v_2 = hs/l, \text{ which is constant.} \tag{3}$$

This is an additional advantage of fixing the curve and the screen, as by observing the depth of the principal band it is easy to tell whether the fringes correspond to a single period or to two or more periods of nearly equal lengths.

Resolving Power—Experiment shows that two periods can just be separated when the principal maximum of one coincides with the first minimum of the other. Therefore, if p and p' are the two periods,

$$p' = hs/v' \qquad \text{(see equation 1)}$$

i.e. $v' = hs/p'$ and by equation (2) is also

$$= hs\left(\frac{1}{p} + \frac{1}{2l}\right) \qquad \therefore \frac{1}{p'} - \frac{1}{p} = \frac{1}{2l}. \tag{4}$$

Accuracy—The middle of the band of fringes can be determined to within about a twentieth of the total depth of the band. Remembering that equation (4) may be regarded as defining half the depth of the band, it is seen that the maximum error in $1/p$ is $1/20l$. This does not, of course, include any error which may be introduced by the irregularities in the curve.

Experimental Comparison with the Results obtained by Calculation—Records of the temperature at Edinburgh from 1764 to 1863, for which the periodogram had already been calculated by Brunt,[3] were examined without previous reference to Brunt's results. All the maxima on the periodogram were easily detected.

IV—THEORY OF THE PERIODOGRAPH WITH A HARMONIC GRATING

The formation of the principal and the subsidiary sets of fringes is best explained by calculating the amplitudes of those produced by a simple periodic curve. Two cases must be distinguished—(1) When the curve is limited in length and the grating is infinite, and (2) when the curve is infinite and the grating is limited.

(1) Limited Curve

Let the curve be represented by $R_0 + R\cos(2\pi t/p - \varepsilon)$, t being zero at the mid point of the curve, and let the fraction of the incident light transmitted at a point on the grating, distant x from the central line, be proportional to $1 + a\cos 2\pi x/S$. Then, in Fig. 2, the intensity of the light falling on a point B of the screen due to a short length, dt, of the curve at T_1, is proportional to—

$$\left\{R_0 + R\cos(2\pi t/p - \varepsilon)\right\}\left\{1 + a\cos 2\pi x/s\right\} dt = dI \text{ (say)}. \tag{5}$$

From Fig. 2 it is seen that—

$$\frac{x+y}{t+y} = \frac{v}{u+v}\,,\ \text{giving } x = \frac{vt - uy}{u+v} \tag{6}$$

$$\therefore dI = \left\{R_0 + R\cos(2\pi t/p - \varepsilon)\right\}\left\{1 + a\cos\left(\frac{2\pi}{s}\cdot\frac{vt-uy}{u+v}\right)\right\} dt$$

Putting $2\pi/p = k$, $\frac{2\pi}{s}\cdot\frac{v}{u+v} = g$, and $\frac{2\pi}{s}\cdot\frac{uv}{u+v} = \delta$, and expanding we get—

$$dI = R_0 dt + R\cos(kt - \varepsilon)\,dt + R_0 a\cos(gt - \delta)\,dt + Ra\cos(kt - \varepsilon)\cos(gt - \delta)\,dt. \tag{7}$$

Now $I = \int_{t=-l}^{t=+l} dI$ = the sum of the following terms (starting from the right of equation 7)—

$$\text{(A)} = Ra\int_{-l}^{+l}\cos(kt - \varepsilon)\cdot\cos(gt - \delta)\,dt.$$

Expressing as the sum of two cosines, integrating, expanding the terms in ε and δ, and collecting up the coefficients, this integral reduces to—

$$\frac{Ra}{k^2 - g^2}\left[\left\{(k-g)\sin(k+g)l + (k+g)\sin(k-g)l\right\}\cos\varepsilon.\cos\delta - \left\{(k-g)\sin(k+g)l - (k+g)\sin(k-g)l\right\}\sin\varepsilon.\sin\delta\right]$$

The coefficient of $\cos \varepsilon . \cos \delta$ may be written—

$$k\left\{\sin (k+g) l+\sin (k-g) l\right\}-g\left\{\sin (k+g) l-\sin (k-g) l\right\}$$
$$=2k \sin (k-g) l+(k-g)\left\{\sin (k+g) l-\sin (k-g) l\right\}$$
$$=2k \sin (k-g) l+2(k-g) \cos kl . \sin gl.$$

Similarly the coefficient of $\sin \varepsilon . \sin \delta$

$$=2g \sin (k-g) l-2(k-g) \cos kl . \sin gl.$$

Combining the terms in $\cos \delta$ and $\sin \delta$ in the usual way gives—

$$(\mathrm{A})=\frac{2Ra \sin (k-g) l}{k^2-g^2}\left\{k^2 \cos^2 \varepsilon+g^2 \sin^2 \varepsilon\right\}^{\frac{1}{2}} . \cos \left\{\delta-\tan^{-1}\left(\frac{g}{k} . \tan \varepsilon\right)\right\}+$$
$$\frac{2Ra(k-g)}{k^2-g^2} . \cos kl . \sin gl . \cos (\delta+\varepsilon).$$

Integrating the other terms of equation (7)—

$$(\mathrm{B})=\int_{-l}^{+l} R_0 a \cos (gt-\delta)\, dt=\frac{2R_0 a}{g} . \sin gl . \cos \delta.$$

$$(\mathrm{C})=\frac{2R}{k} . \sin kl . \cos \varepsilon.$$

$$(\mathrm{D})=2lR_0.$$

Remembering that $\delta=\frac{2\pi}{s} . \frac{u+v}{u} . y$, it is seen that the first part of the first term represents a set of fringes of width $s\left(\frac{u+v}{u}\right)$. These are the principal fringes. Putting $(k-g) l=\gamma$ their amplitude becomes—

$$2lRa . \frac{\sin \gamma}{\gamma} . \frac{(k^2 \cos^2 \varepsilon+g^2 \sin^2 \varepsilon)^{\frac{1}{2}}}{k+g}$$

which is identical in form with the expression for the amplitude at a point on the periodogram.[2] The amplitude is a maximum when $\gamma=0$, i.e. when $k=g$, i.e. when $p=s\left(\frac{u+v}{v}\right)$, and it is zero when $\gamma=\pm\pi$. Outside these limits it fluctuates but is always small. The positions for zero amplitude define the limits of the principal band and lead at once to equation (2), Section III. The maximum amplitude is lRa.

The second part of the first term represents a set of fringes of the same width as the above. The ratio of their maximum amplitude, $2Ra/(k+g)$, to the maximum amplitude, lRa, of the principal fringes is $2/(kl+gl)$ and is therefore small when the products gl and kl are large, i.e. when there are a large number (n) of trial periods of length $2\pi/g$ in the curve. Thus, when $n=6$, since $n=2gl/2\pi$, $gl=6\pi$, and the ratio cannot be greater than about 0·1 whatever the value of k. With an irregular curve, which may be regarded as the sum of a series of periodicities of different lengths and phases, the resultant amplitude of fringes represented by this term will in general always be small, because the phases of the components depend upon the phases of the component periodicities of the curve. The amplitude of the fringes is zero when $gl=n\pi$, i.e. when the curve contains a whole number

of trial periods. Since term number (2) involves only the mean height, R_0, of the curve, and not the variations of height, it represents the fringes mentioned in Section III, which may be regarded as due to overlapping images of the curve. Their amplitude decreases as compared with that of the principal fringes as gl increases, but since R_0 may be greater than R it is not necessarily negligible.

Terms (3) and (4) are independent of y and so represent a uniform illumination of the screen.

(2) Limited Grating

In this case we have to substitute for t in expression (5) in terms of x and integrate over the width ($2d$) of the grating.

If $k' = \frac{2\pi}{p}\left(\frac{u+v}{v}\right)$, $g' = 2\pi/s$, and $\gamma' = (k' - g')d$, the illumination at a point on the screen is found to be proportional to the sum of—

(A) $2dRa \cdot \frac{\sin\gamma'}{\gamma'} \cdot \frac{g'}{g'+k'} \cdot \cos\left(\frac{2\pi}{p} \cdot \frac{u}{v} \cdot y - \varepsilon\right) +$

$$\frac{2}{g'+k'} \cdot \cos g'd \cdot \sin k'd \cdot \cos\left(\frac{2\pi}{p} \cdot \frac{u}{v} \cdot y - \varepsilon\right)$$

(B) $\frac{2R_0 a}{g'} \cdot \sin g'd$

(C) $\frac{2R}{k'} \cdot \sin k'd \cdot \cos\left(\frac{2\pi}{p} \cdot \frac{u}{v} \cdot y - \varepsilon\right)$ and

(D) $2dR_0$.

The first term is similar in form to the corresponding one for the limited curve. The fringes due to the overlapping images of the curve are now absent, but another set (3) has appeared. These would still be produced if the grating were replaced by a rectangular aperture. Since their phase depends upon ε their resultant amplitude is small. They have not in fact been observed in practice. The width of the principal fringes is now proportional to the length of the corresponding period. Hence, the method of secondary analysis described in Section II.

(3) Limiting Conditions

It has been assumed in the above calculations that either the grating or the curve is infinite. In practice both are finite, and it is necessary to define the conditions under which the two expressions for the illumination are true.

Let $q = \left(1 + \frac{u}{v}\right) s$. Then it is easy to see that the curve may be regarded as limited when the number n_g of lines in the grating is greater than the number n_q of periods of length q in the curve. The first expression for the illumination then holds for the $(n_g - n_q)$ fringes in the middle of the screen. Similarly, the grating may be regarded as limited when $n_q > n_g$.

V—HARMONIC GRATINGS

Harmonic gratings may be made by photographing sine curves in the same form as Fig. 1 with a short focus cylindrical lens placed in front of the camera lens. Long sine curves are most easily prepared by drawing on a large scale a master curve containing about ten periods, the area between

the curve and a straight line through the minima being blackened. This is reduced photographically and longer curves are made by mounting a number of prints end to end and again photographing to obtain the final curve clear upon an almost opaque ground. The prints can be mounted with considerable accuracy if reference lines for trimming are ruled upon the original curve; these should cut through the minima, so that, if necessary, the joins can be blocked out easily on the final plate.

In order to prepare the negative from which the gratings are to be printed, the curve is strongly illuminated in the lamp house of the periodograph and a camera set up upon the optical bench accurately parallel to it. The camera is focussed on the illuminated curve and the cylindrical lens (of about an inch focal length) is then placed in position in front of the camera lens and rotated until the resulting fringes on the focussing screen produced by the drawing out of the image by the cylindrical lens are perpendicular to the length of the curve. The cylindrical lens causes a little distortion at the corners of the plate, but this is not serious if a long focus (about 12 in.) camera lens is used. To make gratings of different spacings it is easier and better to use sine curves of different wave lengths rather than to move the camera.

The combination of cylindrical and ordinary lenses produces illumination on the plate proportional to $(1 + a \sin 2\pi x/s)$, but in order to reproduce this photographically it is necessary to give reasonably correct exposure and correct time of development both to the negative and to the positive printed from it.

For the gratings mentioned in Section III the exposure was made sufficient to give a fair deposit of silver in the thinnest parts of the plates without being excessive, the time of development of the negative was arbitrarily fixed, and the corresponding correct development for the positive was found by trial. The positives were tested on the periodograph against a sine curve, and for the best of them the second and third order fringes, though still present, were very faint compared with the first order.

An attempt was, however, made to reduce their amplitudes still further by roughly calibrating the plates. The grating negative was developed for the same time and at the same temperature as a test plate, strips of which had been given a series of increasing exposures. From the test plate several positives were printed and given varying developments. By measuring the densities of the strips of these on a Sanger-Shepherd density meter and plotting the densities for each plate against the logarithms of the negative exposures, a relation between the times of development and the slopes of these characteristic curves was obtained, and from this the time for unit slope and therefore true reproduction was deduced. It was necessary, however, to take account of the fact that the density meter gave the density in diffused light, whereas it is more nearly that in parallel light which matters on the periodograph. This was allowed for by measuring one plate on a Lummer-Brodhun photometer under practically the same conditions as those under which the gratings were to be used and assuming that the ratio of the densities in parallel and diffused light was constant over a short range of development times. The gratings developed for the time found in this way all produced second order fringes, which, however, were too faint to cause trouble in practice, and the third order ones could only be detected after the grating had been set to the calculated position. The gratings were, however, little better than the ones developed by trial, and development for times on

either side of the estimated correct time made little or no difference. It appears to be impossible to eliminate the higher orders altogether, presumably on account of the unevenness of the emulsion or of the development, and there seems to be no advantage in fixing the time of development very accurately.

An alternative to the harmonic grating is a plate upon which have been photographed a number of parallel sine curves, one above the other and in the same phase, each similar to those used in preparing the gratings. The ground glass would be parallel to this plate and would be viewed through a short focus cylindrical lens placed with the axis of the cylinder parallel to the curve. This method has not been tried but it should give the same result as a harmonic grating.

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Shirley Institute
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THE JOURNAL OF THE
TEXTILE INSTITUTE
TRANSACTIONS

3—THE THERMAL CONDUCTIVITY OF TEXTILE MATERIALS AND FABRICS

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The thermal conductivity of textile materials and fabrics has been studied by many observers. Their results have been collected and summarised in the usual works of reference, such as the International Critical Tables, and no useful purpose would be served by attempting afresh to review the extensive literature of the subject. With the exception of the work of Rood[1] and of Sale and Hedrick,[2] measurements of the thermal conductivity of textile materials have hitherto been recorded only on account of their academic interest, or because of some specific use as heat insulators in scientific work or refrigerator practice. From the point of view of the textile technologist, the value of existing data is small. The majority of observers have made no attempt to define the fabrics examined with any exactitude, none of the structural details from which manufacturers would construct or identify a cloth being given. This dissociation of pure science from textile technology is responsible for a number of attempts to make qualitative comparison of the warmth properties of textile fabrics, and this in turn has given rise to controversy regarding the relative merits of the various textile fibres as heat insulators. It is clear that the *qualitative* comparison of fabrics can only indicate their relative merits *as fabrics*, and attempts which have been made to extend the results to the component fibre substance are misguided and misleading.

The purposes of the present investigation are therefore threefold—first, to determine the relative merits of various textile fibres as heat insulators by making observations on loose fibre in various states of compression; second, to determine the influence of trade processes on the warmth properties of the finished fabric; and third, to study the thermal conductivity of as wide a range of fabrics as possible, giving in each case structural details to facilitate identification and reproduction.

It is important at this stage to recognise that the term "specific conductivity" or "thermal conductivity" does not have its usual precise significance when applied to a heterogeneous system such as a fabric. Not only is the transfer of heat accomplished by convection and radiation as well as conduction, but one of these factors, convection, may vary considerably according to the design of apparatus. Results of the greatest value will be obtained when the apparatus is so designed that the convection factor operates in much the same way as when the fabric is actually in use. Since the present investigation is intended to refer mainly to clothing materials worn next to the skin, and covered with other thicknesses of cloth so that free air has no access to them, determinations of thermal conductivity were carried out on fabrics contained between metal plates in an enclosed space,

so as to eliminate convection initiated by external agencies as far as possible. The study of fabrics in use as outer clothing requires a totally different procedure, and the results of this, the second section of the investigation, will be detailed in another paper. The research will be completed by a study of the transparency of fabrics to radiant heat, and it should ultimately be possible to prophesy the warmth of textile fabrics under all possible conditions, merely from a knowledge of their structural details. It must, however, be recognised that such an analysis of the transmission of heat through fabrics takes no account of the fact that the distribution of water through the specimen is different under experimental conditions from that holding under service conditious. The precise significance of the divergence is difficult to estimate, and still more difficult to determine experimentally.

EXPERIMENTAL

Design of Apparatus

The type of apparatus most generally employed by previous observers consists of a modification of the "plate" or "wall" method originally suggested by Lees[3] in his classical paper on the subject of thermal conductivity. This method was not designed particularly for use with textile fabrics, and, as might be expected, their peculiar properties merit the construction of a new form of apparatus. Its design must take account of at least three main requirements. The first of these concerns the measurement of the thickness of the specimen under examination, which is inevitably a small quantity. Only in rare cases does it rise as high as 5 mms., and the majority of fabrics have thicknesses ranging from 0·5 to 2·5 mms., a range which would include most of the fabrics in general use as clothing materials. The exceptions would be finely-woven cotton, silk, and artificial silk fabrics whose thicknesses may be as low as 0·1 mm. It follows that considerable accuracy in observation is required if the percentage error in the thickness measurement is to remain low. The problem is further complicated by the fact that a fabric does not possess a surface in the physical sense, but is bounded at each face by a layer of material whose density merges more or less gradually into that of air. Consequently, the only feasible method of defining the thickness of a fabric is to place it between two plane and parallel plates, and state the distance between them when both are in contact with the fabric. This distance, owing to the compressible nature of the fabric, varies according to the pressure applied, and a complete definition of the thickness must therefore include a statement of the pressure under which it was measured. In most cases up to the present these conditions have not been observed. Yet another difficulty exists in connection with the thickness determination. If the thickness of a fabric is measured under a cycle of pressures, it rarely returns to its original value at the original pressure, the divergence being greater the more slowly the cycle is conducted. In consequence, the thickness of a fabric used in determinations of thermal conductivity must be measured *in situ* at the time of experiment. As a corollary, it becomes evident that the apparatus must be designed so as to support the fabric at constant thickness and not at constant pressure. In certain cases, notably in the work of Griffiths and Kaye,[4] very high pressures of the order of 500 grams per sq. cm. have been used in order to ensure efficient thermal contact between the sample and the hot and cold discs. Such a procedure is not permissible with fabrics, as it is bound to cause abnormal conditions of density and structure in the specimens, thus rendering the results inapplicable to fabrics under normal conditions of use.

The second requirement of the apparatus is determined by the hygroscopic nature of textile materials. Under normal atmospheric conditions, wool contains about 16% of its weight of water, the amount adsorbed being determined by the temperature and relative humidity of the surroundings. A water content of this magnitude cannot be without effect on the thermal properties of the material, and, indeed, Staff[5] has investigated the relation between thermal conductivity and the amount of adsorbed water in a number of cases for wool and cotton. It is evident, therefore, that the apparatus must make provision for the control of the moisture content of the samples under examination. This is best accomplished by total enclosure, but a difficulty arises. In order to produce a measurable heat flow through the specimen, a temperature difference between its faces is essential. Should this temperature difference be large, or the absolute temperature of the hot plate be high, there is a risk of causing highly unequal distribution of moisture in the sample, culminating in the deposition of a moisture film on the colder plate. Unless the samples tested are perfectly dried, this risk must always be present, but it is preferable to avoid the use of dry samples in order to obtain results under approximately normal conditions. In this event, the only method of minimising the risk is to make the heat-detecting mechanism as sensitive as possible, allowing the temperature difference to be reduced to a minimum. Lees' method of measuring thermal conductivity is not well adapted for use under these conditions, as in order to obtain a temperature difference between the hot and cold plates of a sufficient magnitude for accurate measurement, either the temperature of the hot plate must be raised above the safety limit mentioned above, or the thickness of the sample disc must be increased by the superposition of several layers of the material under test. Either expedient is undesirable.

Finally, the apparatus should be capable of use with loose fibre in all stages of compression.

With these considerations in mind, the apparatus shown in Fig. 1 was finally evolved for use in the present investigation. The principle of the method is that of Bunsen's ice calorimeter and the cylindrical brass tank *P* constitutes the main heat reservoir or transmitter of the apparatus. It is filled with water kept at constant temperature by means of the thermostatic equipment inserted through suitable openings in the brass lid. The thermo-regulator *M* is of the type described by Clark,[6] and has been found both sensitive and invariable over long periods of time. The "heat receiver" consists of the two concentric cylindrical calorimeters *A* and *B*. The calorimeter *A* is the one by means of which measurements are actually made, the outer compartment *B* serving the purpose of a guard ring ensuring parallel heat flow through that area of the specimen immediately above calorimeter *A*. It also serves in some measure as a protection for the inner calorimeter against heat leaks from the external environment. As a final precaution to this end the whole apparatus is immersed during use up to the level of the rim *K* in a bath of finely powdered ice mixed with just sufficient water to prevent it from caking hard. The projecting rim *K* attached to the lower flange of the casing serves to prevent the ice from coming into contact with the warmer parts of the apparatus. The cross-sectional area of calorimeter *A*, which is constructed of accurately cylindrical brass optical tubing, was measured carefully before the apparatus was assembled. Both calorimeters are completely filled with distilled water, previously boiled to remove dissolved gases, from which the necessary ice is subsequently

formed. To facilitate freezing and prevent undue supercooling, both calorimeters are provided with short platinum points soldered to the underside of the plate X.

In order to follow the volume changes occurring in the calorimeters, both are provided with outlet tubes passing through rubber stoppers inserted through suitable necks at their lower extremities, the outer calorimeter being fitted with two such openings for convenience in filling. The rubber stoppers are clamped firmly in position by spring clamps (not shown in the figure). The outlet tubes are capillary except for a short section H of wider

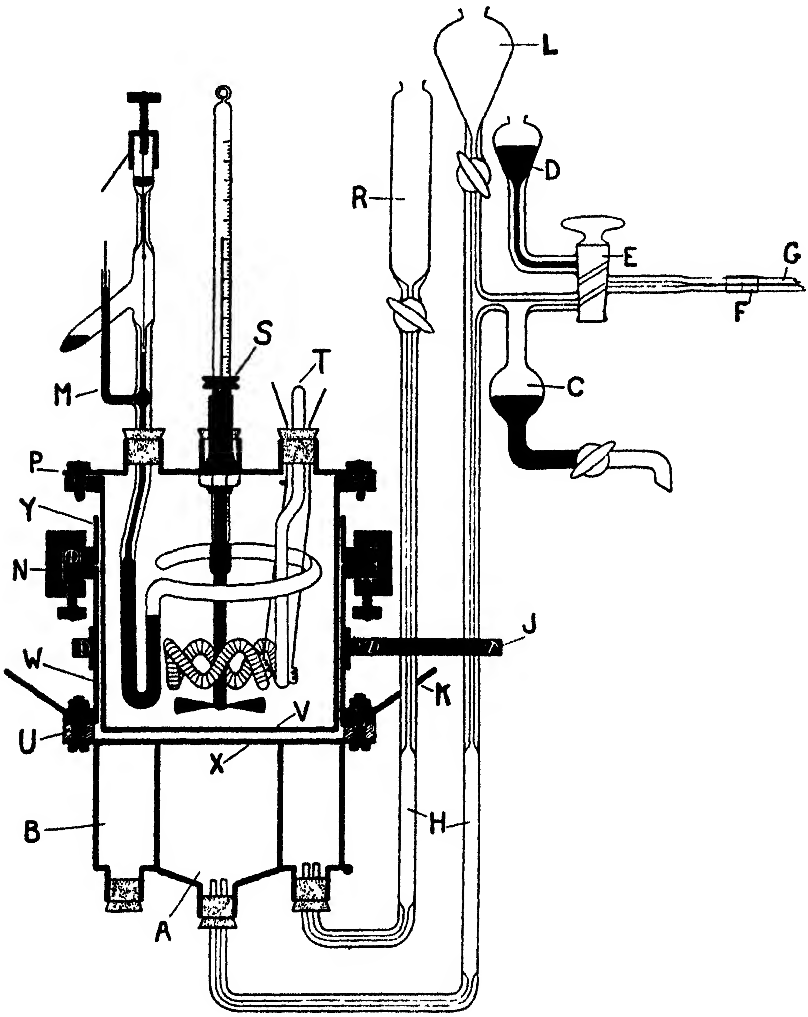

FIG. 1

bore at that part of their length which is subsequently immersed in an outer ice bath. This precaution is necessary to ensure that the water drawn into the calorimeters during measurements attains a uniform temperature of 0° C. The tubes themselves are rigidly attached to the body of the apparatus by means of the clamp J. The outlet from the outer calorimeter terminates simply in the bulb R, in which the water displaced during freezing is accommodated. That from the calorimeter A has a similar bulb L, but is in

addition provided with a side-tube which communicates by way of the tap *E* with a capillary *G* of extremely fine bore, in which the volume changes taking place in the inner calorimeter are actually measured. For this purpose it is provided with hair-line graduations *F* at suitable intervals, the volume of the capillary between successive marks being determined by accurate mercury calibration. By suitable manipulation of the taps, water from the upper bulb *L* may be allowed to fill the capillary. It is then put into direct and only communication with the inner calorimeter, and the rate of arrival of heat in the latter determined by measuring the rate of recession of the water meniscus in the capillary. The meniscus was observed with a telescope, and the time of passage between two marks ascertained by means of a stopwatch.

The specimen under test is contained between the lower plate *X*, which forms the top of the ice calorimeters, and the upper plate *V*, which forms the bottom of the thermostat tank. These two plates were rendered plane and parallel by grinding them down with carborundum powder and oil, first against a steel plate to make them plane, and then *in situ* against each other to make them parallel. They were both finally given a high polish to cut down radiation effects to a minimum. In order to support the thermostat tank in the correct position, with the plate *V* in contact with the upper side of the specimen, a cylindrical casing *W*, in which the tank is a good sliding fit, is attached to the top of the calorimeters, an ebonite washer *U* being inserted in order to prevent undue transference of heat from the thermostat to the guard-ring calorimeter. The joints between ebonite and metal are rendered air- and water-tight by means of piceine cement. The tank may be locked at any point within this casing by means of a sliding sleeve *Y*, carrying a flange similar to that attached to the upper edge of the casing itself. The sleeve is split at one point in its circumference, and is provided with a tightening-screw which permits of its definite location at any point on the tank, whose position is then ensured by clamping the sleeve flange and the case flange together by means of the U-clamps *N*. In this way the upper metal plate confining the specimen may be definitely fixed at any required distance from the lower plate.

As has already been indicated, the thickness of textile fabrics varies considerably with the pressure on the sample at the time of measurement. Consequently, some standard procedure must be adopted in placing the specimen between the plates of the apparatus, to ensure that in all cases the samples used are tested under comparable conditions. This procedure, in the case of fabrics and highly compressed pads of loose fibre, was as follows. The specimen having been laid perfectly flat on the lower plate, the thermostat tank was inserted in the casing, loaded with a weight, and allowed to sink down gradually until the upper plate *V* was in contact with the specimen. The flanges of the sliding sleeve *Y* and of the casing were then clamped together, the sleeve tightened so as to grip the tank firmly, and the weight removed. Under these conditions firm contact between the containing plates and the specimen is ensured. With all the fabrics examined, the pressure applied was always the same, being about 40 g. per sq. cm.

In the case of loose materials at low compression, the required thickness of the specimen necessary for a given density in the apparatus was always known. Hence the sleeve could be set and locked at the correct point before the tank was inserted. All that was then required was to press down the tank until the flanges of the casing and sleeve came into contact, and

clamp them. In each case the thickness of the specimen was obtained by measuring with a micrometer gauge the distance between the upper surface of the flange attached to the tank and the lower surface of that attached to the casing before and after inserting the specimen. Eight measurements were made at marked intervals round the circumference and the mean taken, the required thickness being obtained by difference.

It will readily be appreciated that the apparatus described above conforms to all the criteria specified earlier in the paper. The thickness of the sample can be measured under test conditions, and the pressure on it either varied at will or kept constant at any desired figure from test to test. The humidity of the specimens is readily controlled, and loose materials easily tested. Further, owing to the sensitiveness of the heat-detecting mechanism, in no case was a temperature difference of more than 15° C. necessary between the two faces of the specimen; hence the risk of unequal moisture distribution in the samples is considerably reduced. The quantity actually measured, moreover, is not, as in most other cases, an equilibrium temperature, but a time interval which is susceptible of more accurate mensuration than the former. No so-called constant temperature enclosures are necessary, while the guard-ring principle used enables doubtful assumptions and cumbrous corrections to be dispensed with. Finally, all the fabrics tested were used in single thicknesses only, the superposition of several layers in order to form a sample of sufficient thickness being found unnecessary.

EXPERIMENTAL PROCEDURE

(*a*) *The preliminary treatment of the samples* used was as follows—

All samples of loose materials were cleaned by successive extraction with alcohol and ether in a Soxhlet apparatus, with the exception of acetate silk, which was extracted with petroleum ether only, to remove grease. They were then carded by hand in order to ensure uniform distribution of the individual fibres.

The woven wool fabrics were scoured according to ordinary commercial practice, then subjected to any required finishing process, and finally extracted with alcohol to remove any remaining traces of soap. The knitted hosiery fabrics, both wool and cotton, which were in all cases new samples received from the makers, were also extracted with alcohol. In this connection, it should be noted that Speakman[7] has recently shown that wool treated with hot alcohol retains up to 10% of its weight of alcohol in dry air. The alcohol is not lost *completely* until the material is placed in an atmosphere of over 90% humidity. On this account, certain of the later samples were wetted out with water and dried subsequent to immersion in alcohol. No difference could, however, be detected between samples so treated and those in which traces of alcohol remained.

The cotton fabrics were for the most part tested just as received from the makers, because, owing to the more elaborate finish usually applied to cotton goods, a more valuable test would in this way be made. Certain fabrics were, however, tested both in the untreated condition and also after scouring with soft soap and hot water, followed by extraction with alcohol, in order to ascertain the order of the difference likely to be caused by the presence of finishing materials. The results obtained will be discussed later.

The artificial silk, real silk, and linen fabrics were for the most part examined as supplied by the makers.

Before being tested, each specimen was conditioned for at least 24 hours in a large desiccator completely immersed in a thermostat at 25° C., over a sulphuric acid solution of density 1·272 at 15° C., which according to Wilson,[8] gives a relative humidity of 65% at 25° C.

(*b*) *In making a determination of thermal conductivity*, the following routine was observed.

The sample was removed from the conditioning enclosure, rapidly transferred to a weighing tube, and weighed. Meanwhile the apparatus itself was immersed in its outer ice bath for about an hour in order to cool the water in the calorimeters to near 0° C., and so facilitate the freezing of the necessary ice. This was accomplished by evaporating methylated ether, placed in the thermostat tank, by means of an air blast, the tank being in its lowest position, with the plates *V* and *X* in contact. It was eventually found by experience that once freezing had been initiated by this means, it was better to continue it by employing, instead of ether alone, a mixture of ether and light petroleum spirit of boiling point 40°–60° C. in roughly equal proportions. The risk of causing distortion of the metal parts by too rapid formation of ice was thereby minimised, as the degree of cooling which could be obtained by the use of the above mixture (—7° to —10° C. with the air blast available), whilst sufficient to ensure steady formation of ice in both calorimeters, was considerably less than that obtainable with ether alone (—16° C.).

Having frozen a sufficient quantity of ice, as indicated by the rise of the water level in the bulb attached to the outlet of the guard-ring calorimeter, the apparatus was stood with its lower end immersed to a depth of about half-an-inch in tap water at room temperature. Here it remained for a short time in order that the walls of the calorimeters might become slightly warm and so free the ice blocks inside, thus obviating any tendency for the latter to stick, and ensuring that the ice should always be in contact with the underside of the plate *X*.

In the meantime the thermostat tank was temporarily removed from the casing and rapidly replaced by a duplicate cylinder in order to prevent the access of moist air to the cold inner surface of the casing. The thermostat tank itself was warmed up to room temperature and dried; the duplicate was removed, the sample inserted, and the tank replaced. It was found that if these operations were carried out rapidly there was no tendency for a moisture film to deposit on the inside of the casing or on the lower plate *X*. If, however, this did by chance occur, it was remedied by lowering into the casing a copper gauze cage, fitting close to the walls without actually touching, and filled with granulated calcium chloride. In only a few cases, however, was this device necessary.

The sample having been placed in position, the apparatus was again transferred to the ice bath, the thermostat tank filled with powdered ice to prevent loss of ice in the calorimeters by conduction of heat from the air, and the whole system allowed to stand until temperature equilibrium was attained. It was found that progressive freezing took place in both calorimeters for some time, owing to the fact that the ice, when first formed, was below 0° C. Bunsen states that this effect was observable over a considerable period after freezing, the calorimeter being a glass one of conventional pattern and the freezing agent alcohol cooled to —35° C. In our case, owing to the smaller degree of supercooling employed, and to the use of metal apparatus, temperature equilibrium was reached in 1½ to 2 hours.

At the end of this time the actual measurements were obtained as follows. The thermostat tank, having been emptied of ice, was filled with water,* the lid carrying the thermostatic equipment was placed in position, the stirrer started, and the tank brought up to the required temperature (in all cases 15° C.). For the thicker samples a period of approximately 10 minutes was allowed for the establishment of steady flow conditions through the sample. This period was shown to be adequate by the fact that the times recorded for the passage of the water meniscus between two given points on the capillary had invariably ceased to show a progression in the downward direction at its expiration. In the case of the thinner fabrics the attainment of equilibrium was found to be practically instantaneous. The time taken for the meniscus in the capillary to pass between successive marks was determined several times in succession, and a mean value used to calculate thermal conductivity. The final stage of the determination was to remove the apparatus from the ice bath, empty the thermostat, and measure the thickness of the specimen with a micrometer gauge as already described.

(*c*) *Testing of Apparatus.*

On completion and before use, the apparatus was submitted to various tests to demonstrate its general reliability, and to reveal any mechanical faults which might be present. In the first place, the absence of any leaks from the outer calorimeter to the exterior, and intercommunicating leaks between the calorimeters, was established. The outer ice bath was also shown to be efficient in preventing access of heat to the calorimeters, provided it was well agitated at intervals not exceeding two minutes and was kept replenished with ice. Two further possible sources of error are inherent in the apparatus. The first consists of the asumption that the *inner* faces of the plates V and X are at the temperatures 15° and 0° C. Actually, this is not the case, since it is the outer faces which assume these temperatures. Brass not being a perfect conductor, the inner faces will be at temperatures slightly below 15° and slightly above 0° C., so that the temperature difference between the faces of the specimen is not 15° C. but $(15-x)$° C., where x is a quantity which varies with the thickness and conductivity of the specimen. This error will be at a maximum with thin fabrics, and can readily be calculated. The thickness of the brass plates is 1 millimetre each, and the conductivity of brass is 0·260. The thermal conductivity of fabrics is of the order 1×10^{-4} cals./sq. cm./sec./unit temperature gradient, and as an extreme case we may assume the thickness to be 0·01 cm. With these data it can readily be shown that the percentage error introduced by assuming the temperature difference to be 15° C. is only 0·8 per cent.

The second possible error is that of drainage in the horizontal capillary. It was not anticipated that this would prove a serious matter, but nevertheless it was decided to carry out an experimental test. For this purpose the glass work of the apparatus was modified so as to include the mercury supply bulb D, connected to the capillary via the second arm of the 2-way tap E. Thus as an alternative to water from the bulb L, dry mercury could be allowed to fill the capillary. The trap-bulb C prevented the mercury discharged from the capillary from reaching the metal-work of the ice-containers. A sample of ebonite was placed between the plates, and the following measurements obtained—

* Direct experiment showed that the weight of water filling the thermostat tank was incapable of producing any measurable deformation of the baseplate V, even when the tank was supported well clear of the fabric.

Cross-sectional area of the inner calorimeter=18·20 sq. cm.
Temperature of thermostat=15° C.
Thickness of ebonite=0·576 cm.
Volume of capillary between marks=17·22 cubic mm.
Times for contraction between marks (mean of 10 observations)—
(*a*) With mercury as indicating liquid=99 seconds.
(*b*) With water as indicating liquid=100 seconds.
Conductivity of ebonite=0·000320.*

The drainage error is plainly inappreciable.

The possibility of a constant error in the apparatus and procedure was eliminated by determining the specific conductivity of a blanket cloth having a thickness of 2·24 mm. and an overall density of 0·1916 g/cc. This was found to be $85{\cdot}1 \times 10^{-6}$, and it is satisfactory to note that recalculation of Sale and Hedrick's data[2] for a blanket having a thickness of 2·5 mm. and a density of 0·1728 g/cc. gives the value $81{\cdot}9 \times 10^{-6}$ for its conductivity.

RESULTS

The Thermal Conductivity of Loose Materials

Subsequent to actual manufacture, most textile fabrics are subjected to various "finishing" processes whose aim is to render the material more suitable for use in particular circumstances. Among wool finishing processes are included milling, raising or napping, cutting and pressing, and while they must all influence the warmth-retaining properties of the material, some at least are definitely applied with this end in view, as, for instance, the milling and subsequent raising of blankets. A study of the effect of such processes on the thermal conductivity of fabrics is necessary if we are to gain any practical knowledge which will be of service in designing fabrics for use under prescribed conditions. Most finishing processes, however, result essentially in alterations of the density and thickness of the fabrics operated upon. This is particularly true of wool fabrics in which greater variations in these two quantities are possible than with any other material, owing to the unique structure of the wool fibre itself. Hence a study of the effect of variations of these two factors upon the conductivity of samples of loose materials forms an important preliminary to the study of fabrics. In such experiments the effect of thickness and density upon the conductivity may be studied in its simplest form, without the added complication of a more or less definite structure which is present in all fabrics.

There are four ways in which heat may traverse a mass of fibrous material such as wool or cotton, namely, by radiation from one of the confining surfaces to the other, by convection in the air filling the interstices of the specimen, by conduction through the air and by conduction through the material itself. The "apparent conductivity," i.e. the total transmission of heat by all these agencies in the case of a loose material which is itself a heat insulator, will approximate more or less closely to that of air, the sample being, as it were, for the most part composed of this medium. Although the effect of radiation can be ignored,[9] the convection factor

* This value is in all probability too low, because it was impossible to ensure perfect thermal contact at all points between ebonite and brass. The usual device of smearing the solid under examination with glycerine or other liquid could not be employed, because it would then have been impossible to remove the specimen from the apparatus after measurements had been made. No such difficulties are experienced with fabrics for two reasons—they are extremely flexible and air is an essential part of their composition.

precludes any theoretical prediction of the relations between conductivity and thickness and conductivity and density.

(a) The Relation between Conductivity and Thickness at Constant Density.

The material chosen for these experiments was an Australian merino wool of 80's quality. Two sets of observations were made, the first with wool compressed as far as possible by hand in the apparatus itself, and the second with the material arranged as loosely as possible consistent with uniform distribution. The results are summarised in Tables I and II.

Table I

Thickness of Sample cm.		Density of Sample g./cc.		Specific Conductivity $K \times 10^6$
0·078	...	0·0297	...	68·2
0·154	...	0·0263	...	70·1
0·242	...	0·0238	...	73·2
0·360	...	0·0232	...	79·3
0·493	...	0·0237	...	83·9
0·642	...	0·0234	...	85·0
0·760	.	0·0231	...	88·9
0·978	...	0·0237	...	97·6

Table II

Thickness of Sample cm.		Density of Sample g/cc.		Specific Conductivity $K \times 10^6$
0·123	...	0·1313	...	64·5
0·244	...	0·1651	...	72·3
0·500	...	0·1623	...	83·6
0·739	...	0·1641	...	86·4

(b) The Relation between Conductivity and Density at Constant Thickness.

A consideration of the preceding results led to the adoption of an arbitrary standard thickness of 5 mm. for these experiments, because at this thickness readings could be obtained with sufficient rapidity to ensure reliable results, while the effect of small variations from this standard thickness is negligibly small. Preliminary experiments were made with seven different materials compressed by hand in the apparatus itself, but the maximum density attainable in this way was only 0·1761 g./cc., or approximately one-eighth of that theoretically possible in the case of wool. A number of observations were made with several materials compressed to different degrees, but the variation in conductivity was so small as to be insignificant, and only the values for extremes of density will be quoted (Table III).

Table III

Material	Thickness cm.		Density g./cc.		Specific Conductivity $K \times 10^6$
Australian crossbred wool, 56's quality	0·474	...	0·0127	..	88·0
	0·460	...	0·1761	..	82·9
Australian merino wool, 80's quality	0·493	...	0·0237	...	83·9
	0·500	...	0·1623	...	83·6
Turkey mohair, 5's quality	0·458	...	0·0254	...	80·9
	0·493	...	0·1616	...	81·3
Japanese silk waste	0·485	...	0·0252	...	73·9
	0·498	..	0·1626	...	83·0
Egyptian cotton	0·502	...	0·0122	...	89·0
	0·460	...	0·1681	..	90·6
Viscose silk	0·495	...	0·0235	...	85·9
	0·472	...	0·1590	...	89·1
Acetate silk	0·485	...	0·0242	...	80·5
	0·464	...	0·1732	...	84·4

It is shown later in the paper that the density of fabrics varies from 0·15 to 0·60 g./cc., the vast majority having densities outside the range covered by the preceding experiments. The mechanical construction of the apparatus would not permit of higher values being obtained by the compression *in situ* of a mass of carded fibres, and a separate apparatus was accordingly constructed for use in a hydraulic press. This consisted of a brass casting whose interior was machined to the same diameter as the main apparatus. A solid cylidrical brass plunger was turned to make a very good fit within the casting, which was screwed down by means of projecting lugs to a brass baseplate. The material to be compressed was carded as before, then placed in the cavity of the casting and thoroughly wetted with distilled water. The plunger was placed in position and allowed to rest on the upper surface of the material, thus serving to retain it in position during the subsequent operation of boiling. The whole compression apparatus was immersed in boiling water for approximately 30 minutes in order to bring the wet material up to steam temperature, then rapidly removed, placed in a hydraulic ram, and a sufficient pressure exerted to compress the material within the desired space. Pressures up to 450 lb. per square inch were used. The apparatus was allowed to cool in the ram, the disc of material being afterwards removed and then kept under pressure in a screw press between thick pads of blotting paper until most of the water had been removed. Finally, the pad was transferred to the humidity room (65% relative humidity at 22·2° C.), and allowed a minimum of three days to "condition" before being tested in the apparatus. In the case of wool, the discs of material had to be compressed to thicknesses less than 5 mm. to compensate for the elastic recovery which always took place during conditioning. In consequence, the samples used were not always at the standard thickness when tested, but those which were seriously in error had their conductivities corrected by reference to the conductivity-thickness relationship already obtained. In the case of cotton this difficulty did not arise.

The results obtained with compressed wool pads were consistent and reproducible, but unaccountable variations were at first encountered with compressed cotton. Their cause was finally located in the fact that the fibres in the compressed pads were not distributed entirely haphazardly, but tended to be arranged with their long axes parallel to the faces of the sample. The cause of this orientation lay in the fact that in preparing the cotton for compression it was carded by hand and the carded material stripped from the cards in a series of sheets or laps in which the fibres were definitely placed side by side. It had then been the custom to place a series of laps one upon the other, insert the pile so obtained in the press, and compress the whole, still in the same position, into the space desired. Upon occasion, however, the flat arrangement of the laps mentioned above was more or less interfered with in the operations preceding the actual compression, and the results obtained with such pads showed the variations already mentioned. This explanation was shown to be valid by preparing two pads of the same density, one with the laminated arrangement of the fibres preserved as far as possible, and the other with this arrangement destroyed by turning the pile of card laps on its side before compressing. The results obtained with these two samples were as follows—

Sample	Density g./cc.	Thickness cm.	Specific Conductivity $K\times10^6$
Laminated	0·276 ...	0·459 ...	85·7
"Unlaminated" ...	0·275 ...	0·467 ...	92·6

The results given in Table IV were obtained with samples in which every endeavour was made to destroy preferential orientation of the fibres.

Table IV

Material	Thickness cm.	Density g./cc.	Specific Conductivity $K \times 10^6$	Specific Conductivity corrected to Thickness of 5 mm. $K \times 10^6$
64's Merino Wool	0·469	0·025	78·5	
	0·497	0·070	79·1	
	0·451	0·128	79·9	
	0·459	0·176	81·3	
	0·571	0·200	82·3	
	0·340	0·362	88·4	94·7
	0·516	0·416	97·0	
	0·249	0·503	101·6	112·6
	0·312	0·618	115·7	123·8
	0·201	0·811	134·2	146·7
	0·240	0·903	155·5	166·7
Egyptian Cotton	0·502	0·0122	89·0	
	0·490	0·0588	86·1	
	0·500	0·0988	83·6	
	0·474	0·1294	87·5	
	0·460	0·1681	90·6	
	0·477	0·270	93·2	
	0·467	0·275	92·6	
	0·538	0·385	99·5	
	0·518	0·612	135·2	
	0·510	0·622	133·1	
	0·538	0·901	169·3	
	0·512	1·028	268·6	
Viscose staple fibre	0·495	0·0235	85·9	
	0·482	0·0239	86·0	
	0·490	0·0472	81·7	
	0·495	0·0696	79·9	
	0·477	0·0970	82·0	
	0·482	0·1196	84·1	
	0·479	0·1386	80·8	
	0·472	0·1590	89·1	
	0·326	0·3434	101·0	
	0·371	0 4656	120·1	
	0·345	0·6052	134·9	
	0·361	0·7893	180·6	
	0·358	0·7991	181·0	
	0·416	0·8030	183·5	
	0·370	1·199	258·2	
	0·366	1·188	298·6	

The preceding observations possess a certain intrinsic interest, and serve also to show the superiority of wool as an insulator over cotton and viscose silk (Fig. 2). It is, however, difficult to assess their value in relation to the thermal conductivity of fabrics, because there must always remain some doubt whether the fibre arrangement is precisely the same with different fibres. Fortunately, the development of the study of fabrics, to be discussed later in the paper, led to the discovery of a more reliable method of evaluating the relative merits of the several textile fibres as heat insulators, and the work on compressed pads of loose fibre was accordingly abandoned.

The Thermal Conductivity of Wool Fabrics

It has so far been shown that the thermal conductivity of heterogeneous systems such as compressed pads of textile fibres is dependent on the thickness of the sample tested and to a smaller extent on its density. A study of the effect of trade finishing processes on these two variables, and the corresponding changes in the thermal conductivity of fabrics, was therefore undertaken. Unfortunately, the investigations had to be limited to wool

fabrics because of the absence of suitable machinery for manipulating the remaining textile fibres. As a preliminary to the study of finishing processes, the effect of weave structure on thermal conductivity was determined.

(*a*) *The Effect of Weave Structure on Thermal Conductivity.*

Two series of fabrics were constructed, the first consisting of seven fabrics of diverse weave, woven in the same loom from the same warp and to as nearly as possible the same loom particulars. This series will be designated

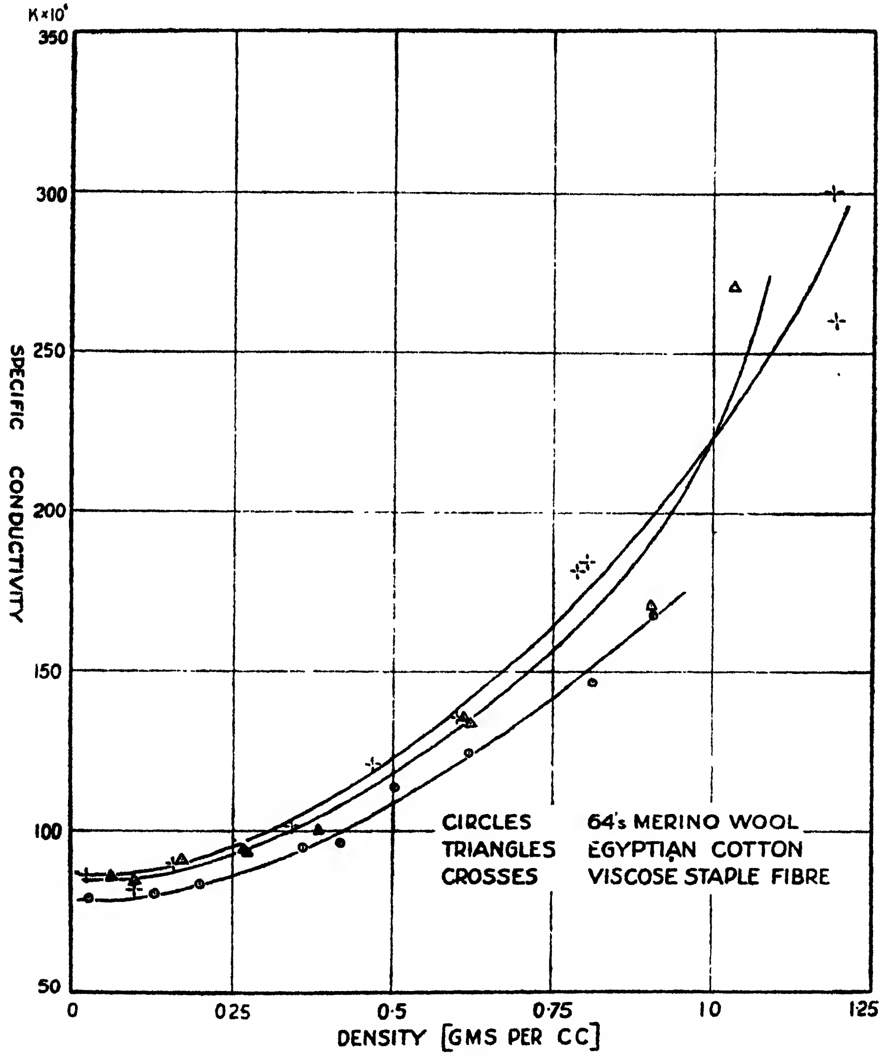

Fig. 2

as W¹. Owing to the differing properties of the weaves employed, the fabrics finally produced differed slightly from one another in particulars, on account of the different shrinkage occasioned in scouring. The results obtained are given in Table V, full particulars of the fabrics being shown in the appendix. The second series consisted of six much thicker fabrics, also woven in the same loom and from the same warp. In this case the various pieces were milled to some extent in order to bring the particulars

of the finished fabrics more nearly into agreement. This series is identified as W^2, and the results obtained are given in Table VI.

Table V

No. of Fabric	Weave	Thickness cm.	Density g./cc.	Specific Conductivity $K \times 10^6$
$W^1 1$	2/2 Twill	0·076	0·359	84·6
$W^1 2$	4/4 Twill	0·093	0·338	90·8
$W^1 3$	2/2 Twilled Hopsack	0·076	0·416	88·7
$W^1 4$	2/2 Hopsack	0·071	0·406	85·4
$W^1 5$	Broken Crow	0·068	0·423	90·0
$W^1 6$	3/1 Repp	0·071	0·428	88·1
$W^1 7$	3/1 Twill	0·076	0·366	89·1

Table VI

No. of Fabric	Weave	Thickness cm.	Density g./cc.	Specific Conductivity $K \times 10^6$
$W^2 1$	Honeycomb	0·419	0·158	95·4
$W^2 2$	4/4 Warp Rib	0·264	0·285	98·3
$W^2 3$	4/4 Hopsack	0·266	0·245	93·3
$W^2 4$	Plain	0·193	0·271	87·9
$W^2 5$	3/1 Twill	0·306	0·228	96·3
$W^2 6$	Weft Cord	0·301	0·248	97·6

It is clear from these measurements that weave structure affects the thermal conductivity of a fabric only indirectly through the variations which it is able to cause in the thickness and density. .

(*b*) *The Effect of the Milling Process on Thermal Conductivity.*

Owing to the independence of conductivity and weave structure, it is possible to study the effect of wool finishing processes on the warmth-retaining value of a single fabric with the certain knowledge that the results will be of general application. Probably the most important of such processes is that of milling. Hence the following experiments were carried out with a view to determining to what extent and in what manner this process affects the thickness, density, and conductivity of wool fabrics.

The material used was a white worsted cloth of twill weave, described in the table given in the Appendix under number $M^1 1$. From this material two ranges of samples were prepared. The first consisted of eight pieces milled to varying extents in the fulling stocks, potash soap being the milling agent; the second, of a further eight pieces milled in the milling machine with hard (soda) soap. Both series are necessary, as the effect produced by the two methods is not the same. The fulling stocks tend to produce a fluffier appearance on the face of the cloth, combined with greater thickness and softness of handle, than the milling machine. The extent of milling in both cases was ascertained by measuring before and after the process the area of a large rectangle marked out on the sample by coloured stitching. The percentage decrease in area was taken as a measure of the extent of the milling process. The results obtained in the two cases are summarised in Tables VII and VIII.

Table VII

Samples Milled with Soft Soap in the Fulling Stocks

No. of Fabric	Degree of Milling (% Contraction of Initial Area)	Thickness cm.	Density g./cc.	Specific Conducitivity $K \times 10^6$
$M^1 1$	0	0·124	0·328	97·6
$M^1 8$	7·90	0·162	0·258	94·9
$M^1 9$	11·79	0·157	0·277	94·0
$M^1 6$	12·31	0·157	0·279	96·1
$M^1 2$	19·77	0·188	0·262	90·1
$M^1 4$	31·94	0·233	0·253	94·4
$M^1 3$	32·43	0·226	0·250	95·0
$M^1 7$	41·34	0·224	0·283	96·4
$M^1 5$	44·06	0·254	0·268	95·2

Table VIII

Samples Milled with Hard Soap in the Milling Machine

No. of Fabric	Degree of Milling (%Contraction of Initial Area)	Thickness cm.	Density g./cc.	Specific Conductivity $K \times 10^6$
$M^2$8	0	0·117	0·343	97·7
$M^2$1	7·48	0·147	0·295	93·1
$M^2$2	11·85	0·155	0·279	92·3
$M^2$3	19·61	0·162	0·287	94·9
$M^2$4	27·05	0·174	0·300	91·3
$M^2$7	30·65	0·183	0·301	93·8
$M^2$6	34·60	0·193	0·303	96·2
$M^2$5	40·61	0·204	0·316	96·9

A study of these results reveals the following points of interest. In both series the initiation of the milling process is marked by an increase in thickness, a decrease in density, and a drop in conductivity. This is in keeping with the production of a fibrous cover on the face of the cloth, which, by reason of the layer of air entrapped by it, tends to lower the conductivity of the material. As shrinkage progresses the thickness of the samples in series M^1 increases, but the conductivity and density remain approximately constant. The raising of a cover seems to counterbalance the slight tendency of the fulling process to raise the density, and so keeps the conductivity constant. In series M^2 the same effect is present but to a lesser degree. In this case not only is the thickness finally attained by the fabric less, indicating a smaller amount of cover, but the density shows a tendency to rise as milling progresses; the covering effect is no longer sufficient to neutralise the increase in density and the conductivity rises.

It is of considerable interest to study the conductivity of a range of fabrics milled in the same manner as the foregoing, but in which the covering effect is absent. This may be done in practice by first milling the samples as before, and then running them over the cutting machine in order to remove any cover which may have been formed during milling.

(*c*) *The Conductivity of Fabrics Milled and Subsequently Cut.*

Samples were taken from each of the fabrics comprising the series M^2, and these were then run through the cutting machine together, so that the surface of each was cropped to the same extent as judged by appearance. The results obtained from the series of samples so prepared are indicated in Table IX. In general, the conductivity of these fabrics is distinctly higher than those from which they are derived. This serves to confirm the suggestion already advanced as to the effect of a fibrous layer in reducing the conductivity of a fabric.

Table IX

Fabric No.	Degree of Milling (%Contraction of Initial Area)	Thickness cm.	Thickness of Cover Removed mm.	Density g./cc.	Specific Conductivity $K \times 10^6$
MC.8	0	0·098	0·19	0·382	99·6
MC 1	7·48	0·111	0·36	0·352	98·0
MC.2	11·85	0·117	0·38	0·354	101·6
MC.3	19·61	0·122	0·40	0·356	100·9
MC.4	27·05	0·129	0·45	0·362	103·3
MC.7	30·65	0·132	0·51	0·361	95·2
MC.6	34·60	0·139	0·54	0·360	100·0
MC.5	40·61	0·139	0·65	0·385	100·8

(*d*) *The Conductivity of Raised Fabrics.*

The foregoing experiments are unanimous in indicating that a fluffy surface or cover, if developed on a fabric, tends to lower its conductivity.

Hitherto, however, we have considered only the cover which is raised upon cloths as an incidental result of the milling process. This very cover is formed on many types of fabrics to a far greater degree by the process of raising, and in many cases with the express intention of rendering the fabrics more valuable from a warmth-rètaining standpoint. It is of interest therefore to carry the investigations one stage further, and determine experimentally the effect of the raising process upon the fabric itself and upon its conductivity.

For this purpose a further supply of the same cloth (No. $M^1 1$) was obtained and divided into suitable sample lengths. These lengths, nine in number, were then milled together in the milling machine to 30% contraction. This was done to provide a firm structure for raising, so that the samples which would subsequently be severely raised might not suffer an undue amount of damage in the process; and also to simulate as far as possible normal commercial practice. After milling, the samples were placed on the card-wire raising machine, which was run at its lowest speed. One sample was removed initially, and kept as the unraised standard. The remainder were taken from the machine at intervals, the last to be removed having run long enough for the raising process to have reached its limit.

The results obtained from this series of samples, given in Table X, show an immediate increase in thickness and decrease in density at the start of the process. The conductivity also drops, which again confirms the conclusions already arrived at. After a time, however, the reverse changes appear to occur, the thickness showing a continuous decrease while the density and thermal conductivity tend to increase. This undoubtedly indicates that from sample R4 onwards the machine is not actually raising the cloth at all, but is, in fact, removing the cover already formed. As a matter of interest, a piece of the sample R9 was removed after raising, and run through the cutting machine in the same way as those in the MC series, so as to remove the whole of the raised cover. The resulting fabric had a thickness of 1·39 mm., an overall density of 0·371 g./cc, and a specific conductivity of $101{\cdot}4 \times 10^{-6}$.

Table X

No. of Fabric	Degree of Raising (Times Round the Machine)	Thickness cm.	Density g./cc.	Specific Conducitivity $K \times 10^6$
R.5	0	0·167	0·334	97·9
R 1	1	0·195	0·284	94·2
R.2	2	0·188	0·291	92·5
R.3	4	0·190	0·287	94·3
R.4	6	0·193	0·283	93·3
R.6	8	0·185	0·292	93·5
R.7	11	0·183	0·298	94·2
R.8	15	0·178	0·308	93·8
R.9	20	0·180	0·296	94·4

(e) The Conductivity of Knitted Wool Fabrics.

For these experiments samples were obtained from as many external sources as possible in order to obtain a representative selection of the types at present in use. The results are arranged in order of increasing thickness of fabric in Table XI to demonstrate the increase in conductivity with thickness. As was to be expected, the range of densities encountered in knitted fabrics is smaller in extent than in the case of woven materials.

Table XI

Fabric No.	Type of Raw Material Used	Thickness cm.	Density g./cc.	Specific Conductivity K × 10⁶
K.2	Fine crossbred	0·051	0·331	73·5
P.1	—	0·054	0·266	66·1
P.4	—	0·058	0·318	76·1
K.8	Fine crossbred	0·061	0·288	76·0
K.10	Dry spun Botany	0·063	0·283	73·2
K.6	Medium crossbred	0·066	0·287	75·4
P.2	—	0·073	0·227	74·2
K.3	Fine crossbred	0·078	0·273	81·7
K.7	Fine crossbred	0·081	0·286	83·3
K.11	Dry spun Botany	0·083	0·253	83·4
K12	Dry spun Botany	0·091	0·273	81·1
K.1	Fine crossbred	0·101	0·255	83·3
P.3	—	0·101	0·281	86·1
K.5	Medium crossbred	0·106	0·255	85·4
K.9	Fine crossbred	0·117	0·241	88·5
E.8	Cheviot	0·254	0 220	99·2

The Thermal Conductivity of Fabrics Composed of Fibres other than Wool

The fabrics used in this section of the investigation were obtained from external sources, and precise details of the finishing processes to which they had been subjected are not therefore available. The structures of the finished fabrics have, however, been ascertained as far as possible by analysis, particulars of which will be found in the Appendix.

(*a*) *The Conductivity of Cotton Fabrics.*

The results obtained on woven cotton fabrics are shown in Table XII, and there is an evident tendency for the conductivity to rise with increasing thickness of the fabric.

Table XII

Fabric No.	Thickness cm.	Density g./cc.	Specific Conductivity K × 10⁶
F 5	0·018	0·752	68·4
C.5	0·018	0·657	66·1
O.1	0·021	0·528	67·3
F.3	0·023	0·615	78·2
F.5A	0·023	0·602	83·4
C.4	0·023	0·555	75·4
F.3A	0·029	0·481	89·8
F.2	0·030	0·698	105·3
F.2A	0·030	0·695	102·7
F.4	0·036	0·501	98·2
F.1	0·038	0·567	96·9
F.1A	0·043	0·504	97·1
F.4A	0·043	0·398	104·0
C.3	0·043	0·341	85·8*
C.2	0·048	0·363	100·2
O.4	0·054	0·362	92·4*
C 1	0·068	0·260	99·1

* Samples had been napped, and possessed a fluffy surface.

Taking certain results in detail, the effect of raising can again be seen in samples C.3 and O.4, whose conductivity is decidedly below the average observed in this region of thickness. The samples comprising series F (F.1 to F.5) all had the appearance of being rather heavily finished, and details of the same fabrics after soap scouring to remove finishing materials are given under the notation F.1A to F.5A. As might be expected, the effect of scouring is to increase the thickness and decrease the density of the fabrics.

Cotton fabrics specially designed for underwear purposes were also studied, three samples of knitted fabrics and three of cellular fabrics being examined. The results are summarised in Table XIII, and it is evident that the cellular structure has the advantage over knitted fabrics in so far as heat-retention in stagnant air is concerned.

Table XIII

No. of Fabric	Thickness cm.	Density g./cc.	Specific Conductivity $K \times 10^6$
Cellular Fabrics—			
A.7	0·076	0·172	95·1
A.6	0·081	0·185	106·3
A.1	0·098	0·197	104·8
Knitted Fabrics—			
V.2	0·066	0·229	108·8
V.3	0·073	0·263	118·2
V.1	0·088	0·218	114·1

It will be noted that the values obtained for the conductivity of cotton materials are, on the whole, greater than those found for wool fabrics, despite the fact that the thicknesses are, generally speaking, less.

(*b*) *The Conductivity of Silk Fabrics.*

Measurements were made on two woven and two knitted samples of real silk fabrics. The data obtained are given in Table XIV, but the value obtained for the conductivity of the first fabric may be unreliable owing to its very small thickness.

Table XIV

Fabric No.	Thickness cm	Density g./cc.	Specific Conductivity $K \times 10^6$
Woven fabrics—			
O.12	0·011	0·749	49·7
O.13	0·018	0·603	64·4
Knitted fabrics—			
O.14	0·101	0·285	114·0
O.15	0·038	0·379	76·4

(*c*) *The Conductivity of Artificial Silk Fabrics.*

With two exceptions, the artificial silk fabrics examined were knitted materials. Sample O.8 was a woven cuprammonium silk fabric; O.3 was knitted from hollow-fibre viscose; and K.4 was a similar structure made from ordinary solid-fibre viscose, for comparison; O.10, O.9, and O.11 were knitted cellulose acetate silk fabrics, while S.3 was a woven fabric of viscose silk, the yarn being made on the woollen system from short fibre.

Table XV

Fabric No.	Thickness cm.	Density g./cc.	Specific Conductivity $K \times 10^6$
O.8	0·018	0·675	72·9
O.3	0·026	0·370	75·4
K.4	0·029	0·499	91·3
O.10	0·029	0·394	72·6
O.9	0·033	0·344	68·3
O.11	0·044	0·252	67·7
S.3	0·054	0·391	83·6

(*d*) *The Conductivity of Linen Fabrics.*

Only one linen fabric was examined, the following figures being obtained.

Fabric No.	Thickness cm.	Density g./cc.	Specific Conductivity $K \times 10^6$
O.5	0·029	0·568	86·8

(e) The Conductivity of Mixture Fabrics.

Fabrics composed of a mixture of wool and cotton have been in use for a considerable time, and have found many applications. In recent times, and more particularly since the artificial fibres came into prominence, other mixtures, such as cotton with artificial silk, have been produced in order to combine to some extent the excellent manipulative properties of wool and cotton with the undoubted decorative advantages of artificial silk. Such mixtures are in fairly extensive use as clothing materials, and it appeared necessary to examine at least a small selection of fabrics of this type. Of the eight mixture fabrics obtained, four were cellular underwear materials (A.2 to A.5), the first two being wool-cotton mixtures. S.1 and S.2 were suitings composed of viscose and wool yarns in which the two fibres were scribbled together in manufacture. E.7 was a cotton suiting, the structure being a warp-backed one in which the backing threads contained the wool fibres. V.4 was a knitted fabric composed of two distinct yarns, one of wool and one of cotton, the structure being such that the fabric possessed a woollen exterior and a cotton interior face. Details of the analysis of these fabrics and the results obtained are given in the following table.

Table XVI

Fabric No.	Composition of Material	Thickness cm.	Density g./cc.	Specific Conductivity $K \times 10^6$
A.5	Cotton viscose	0·048	0·280	87·6
A.3	Wool 54·3%, cotton 45·7%	0·091	0·164	93·2
A.4	Cotton viscose	0·098	0·165	93·7
A.2	Wool 55·7%, cotton 44·3%	0·119	0·159	93·7
S.1	Wool 33·1%, viscose 66·9%	0·043	0·427	82·8
S.2	Wool 27·8%, viscose 72·2%	0·043	0·429	83·4
E.7	Wool 18·9%, cotton 81·1%	0·068	0·546	114·2
V.4	Wool 41·8%, cotton 58·2%	0·122	0·211	96·0

It will be noted that the conductivities of the cellular fabrics are distinctly lower than those of similar materials made from cotton only; and that the knitted fabric V.4 has decided advantages over the all-cotton knitted fabrics V.1, V.2, and V.3 (Table XIII).

DISCUSSION OF RESULTS

Up to the present attention has been confined simply to the value of the specific conductivity of a fabric and its relation to the physical characteristics of the structure. The value of a fabric as a heat-insulator is, however, not determined solely by the specific conductivity, and a better index of the fabric's worth would be the quantity of heat transmitted in a given time by the material when the two faces are maintained at given temperatures. The following discussion is therefore concerned mainly with an arbitrary quantity, called for convenience "total heat loss," which is defined as the quantity of heat, in calories, passing through unit area of the fabric in unit time, when one face is maintained at 0° C. and the other at 15° C.

If the specific conductivity of fabrics were a constant quantity, the total heat loss would be inversely proportional, and the utility of a fabric directly proportional to its thickness. It has, however, been shown that the specific conductivity of fabrics is a function of at least three variables; their density and thickness and the nature of the constituent fibres. The total heat loss is obviously affected by the same factors.

The term density, as applied to a fabric, requires special consideration. It is, of course, defined as the average weight of solid material per unit volume

of the heterogeneous system, the volume being measured under standard pressure in the apparatus, as already described. Such a quantity must be used with care in comparing fabrics, for it is possible to obtain the same mean density in a variety of ways. For example, one fabric may have a very open weave and extremely hard-twisted yarns, and another a fairly close weave and soft yarns. Fortunately, the degree of heterogeneity of fabrics is not markedly variable, and the influence of density on thermal conductivity is, in any event, relatively small. In consequence, it has been found possible to express the "total heat loss" for the whole range of wool fabrics examined in general terms as a function of thickness and density.

If the thermal conductivity of fabrics were independent of thickness, the total heat loss would be inversely proportional to thickness, and the relation between these two quantities would be represented by a rectangular hyperbola as shown in curve I, Fig. 3. Actually, the conductivity increases with increasing thickness, and the relation between total heat loss and thickness under these conditions will be of the type shown in curve II, Fig. 3. Both curves are hyperbolic in form, but are different in this respect, that whereas in the case of curve I a straight line would be obtained passing through the origin (curve I, Fig. 4), when the reciprocal of total heat loss

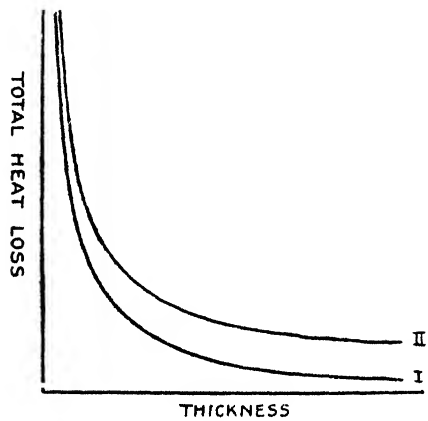

FIG. 3

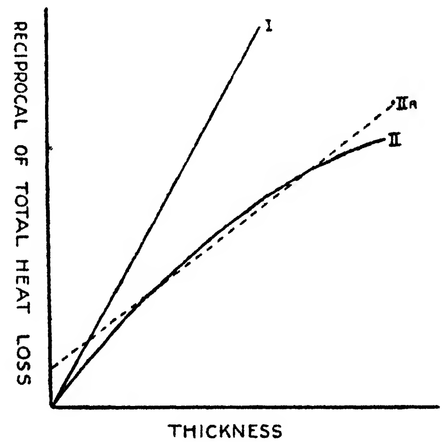

FIG. 4

is plotted against thickness, the corresponding reciprocal graph in the case of curve II would be a curve, as shown in curve II, Fig. 4. In practice, however, owing to the fact that the lower values of thickness are missing, it is found that the reciprocal graph approximates very closely to a straight line having a positive intercept on the reciprocal heat-loss axis, as shown in the dotted curve IIA, Fig. 4. A straight line is actually the best curve which can be drawn through the experimental points (see Fig. 5). The preceding analysis is true only for fabrics of constant density, but while it is known that specific conductivity and total heat loss increase with increasing density, the precise effect of density is best deduced from the experimental results for the fabrics themselves.

All the measurements made on wool fabrics are summarised in Table XVII in order of increasing density. These were sub-divided into groups within which the variation of density was small, as shown by the following figures—

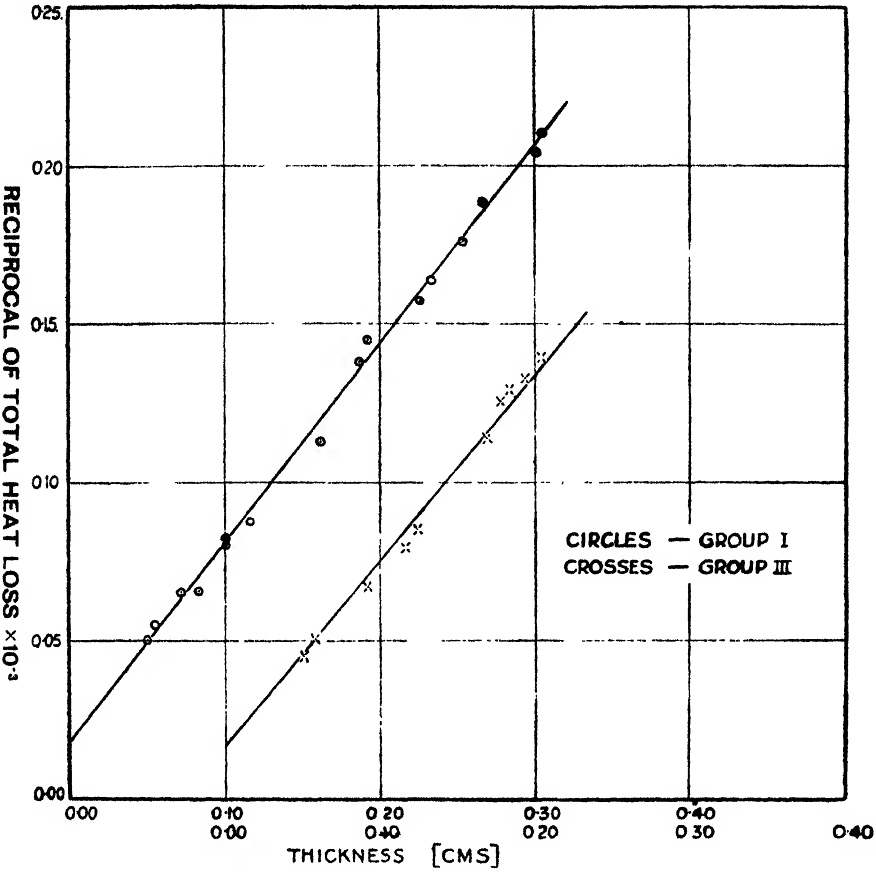

FIG. 5

Group		Density Range (g./cc.)		Mean Density (g./cc)
I	...	0·228—0·268	...	0·252
II	...	0·271—0·300	...	0·286
III	...	0·301—0·343	...	0·322
IV	...	0·352—0·389	...	0·366
V	...	0·406—0·428	...	0·417

Within each group a linear relationship holds between the reciprocal of total heat loss and thickness. The curves for groups I and III are reproduced in Fig. 5, and it will be seen that the distribution of the individual points about the mean lines is distinctly good. From these lines it is clear that the gradient decreases with increasing density, and that the intercept on the axis of ordinates is approximately constant. The value of the mean intercept was obtained from the two strongest lines, those for groups I and II, and was found to be 16·0. Each line was corrected to this intercept, and the following five equations deduced for the relation between total heat loss (H) and thickness (*d*) at different densities.

Mean Density g./cc.		Equation
0·252	...	1/H=16+640d.
0·286	...	1/H=16+620d.
0·322	...	1/H=16+595d.
0·366	...	1/H=16+538d.
0·417	...	1/H=16+535d.

A linear relationship holds between the coefficient of d and density (Δ) with the exception that the point at density 0·366 is in error. The five equations can therefore be reduced to one general form which may be regarded as an expression for the warmth of a fabric in terms simply of its thickness and density—

$$1/H = 16 + (801 - 639\Delta)d.*$$

The validity of the equation is indicated by the comparison of experimental and calculated values of total heat loss given in columns 5 and 6 respectively of Table XVII. With the exception of two fabrics, E.2 and E.1, the formula holds good within very narrow limits for all the types of fabric in common use as clothing materials, and by its use a good approximation to the true value of a fabric as a heat insulator in stagnant air can be obtained from measurements of thickness and density only.

Table XVII

Fabric No.	Density g./cc.	Thickness cm.	1 / Heat Loss (exptl.)	Heat Loss (exptl.) Cals/Sec/ sq. cm.	Heat Loss (calc.) Cals/Sec/ sq. cm.	% Error
W²1	0·158	0·419	0·2933 × 10³	3·41 × 10⁻³	3·23 × 10⁻³	-5·28
B.1	0·161	0·259	0·2045	4·89	5·08	+3·89
B.3	0·174	0·229	0·1862	5·37	5·75	+7·08
E.4	0·180	0·101	0·0899	11·12	11·72	+5·39
B.2	0·192	0·224	0·1754	5·70	5·96	+4·56
E.8	0·220	0·254	0·1706	5·86	5·45	−6·99
P.2	0·227	0·073	0·0656	15·25	15·65	+2·62
W²5	0·228	0·306	0·2119	4·72	4·62	−2·22
K.9	0·241	0·117	0·0881	11·35	10·91	−3·88
W²3	0·245	0·266	0·1901	5·26	5·34	+1·52
W²6	0·248	0·301	0·2058	4·86	4·78	−1·64
M¹3	0·250	0·226	0·1585	6·31	6·21	−1·58
M¹4	0·253	0·233	0·1645	6·08	6·06	−0·33
K.11	0·253	0·083	0·0663	15·08	14·49	−3·92
K.1	0·255	0·101	0·0809	12·37	12·44	+0·57
K.5	0·255	0·101	0·0828	12·08	12·44	+ 2·98
M¹8	0·258	0·162	0·1138	8·79	8·40	− 4·44
M¹2	0·262	0·188	0·1391	7·19	7·40	+2·92
P.1	0·266	0·054	0·0544	18·37	19·96	+8·67
M¹5	0·268	0·254	0·1779	5·62	5·68	+1·07
W²4	0·271	0·193	0·1464	6·83	7·29	+6·73
K.3	0·273	0·078	0·0637	15·71	15·43	−1·78
K.12	0·273	0·091	0·0748	13·38	13·70	+2·39
M¹9	0·277	0·157	0·1114	8·98	8·77	−2·34
M¹6	0·279	0·157	0·1089	9·18	8·79	−4·25
M²2	0·279	0·155	0·1120	8·93	8·88	−0·56
P.3	0·281	0·101	0·0782	12·79	12·93	+1·10
M¹7	0·283	0·224	0·1541	6·46	6·46	0·00
R.4	0·283	0·193	0·1379	7·25	7·37	+1·66
K.10	0·283	0·063	0·0573	17·44	18·15	+4·07
R.1	0·284	0·195	0·1379	7·25	7·30	+0·69
W²2	0·285	0·264	0·1792	5·58	5·57	−0·18
K.7	0·286	0·081	0·0649	15·42	15·13	−1·88
R.3	0·287	0·190	0·1342	7·45	7·50	+0·67
M²3	0·287	0·162	0·1138	8·79	8·62	−1·93
K.6	0·287	0·066	0·0583	17·15	17·62	+2·74
K.8	0·288	0·061	0·0535	18·69	18·65	−0·21
E.3	0·289	0·275	0·1802	5·55	5·39	−2·88
E.2	0·291	0·100	0·0697	14·35	12·90	−10·1

* Cf. Sale and Hedrick, *loc. cit.* p. 543. These authors find a relationship between "thermal resistance" and thickness of blankets, which is essentially similar to that described in this paper.

Table XVII—*continued*

Fabric No.	Density g./cc.	Thickness cm.	$\frac{1}{\text{Heat Loss (exptl.)}}$	Heat Loss (exptl.) Cals/Sec/ sq. cm.	Heat Loss (calc.) Cals/Sec/ sq. cm.	% Error
R.2	0·291	0·188	$0{\cdot}1355 \times 10^3$	$7{\cdot}38 \times 10^{-3}$	$7{\cdot}60 \times 10^{-3}$	+2·98
R.6	0·292	0·185	0·1319	7·58	7·71	+1·71
M^{2}1	0·295	0·147	0·1053	9·50	9·43	−0·74
R.9	0·296	0·180	0·1271	7·87	7·93	+0·76
R.7	0·298	0·183	0·1295	7·72	7·82	+1·29
M^{2}4	0·300	0·174	0·1271	7·87	8·20	+4·19
M^{2}7	0·301	0·183	0·1300	7·69	7·85	+2·14
M^{2}6	0·303	0·193	0·1337	7·48	7·51	+0·40
R.8	0·308	0·178	0·1264	7·91	8·10	+2·40
M^{2}5	0·316	0·204	0·1404	7·12	7·23	+1·54
P.4	0·318	0·058	0·0508	19·68	19·73	+0·25
M^{1}1	0·328	0·124	0·0848	11·80	11·20	−5·09
K.2	0·331	0·051	0·0462	21·63	21·71	+0·37
R.5	0·334	0·167	0·1138	8·79	8·76	−0·34
W^{1}2	0·338	0·093	0·0683	14·65	14·20	−3·07
M^{2}8	0·343	0·117	0·0799	12·52	11·89	−5·03
MC.1	0·352	0·111	0·0755	13·24	12·51	−5·51
MC.2	0·354	0·117	0·0768	13·03	12·02	−7·75
MC.3	0·356	0·122	0·0806	12·41	11·63	−6·29
W^{1}1	0·359	0·076	0·0599	16·69	16·83	+0·83
MC.6	0·360	0·139	0·0926	10·79	10·48	−2·87
MC.7	0·361	0·132	0·0925	10·81	10·95	+1·29
MC.4	0·362	0·129	0·0833	12·01	11·17	−6·99
W^{1}7	0·366	0·076	0·0569	17·58	16·92	−3·75
R.10	0·371	0·139	0·0920	10·87	10·59	−2·57
MC.8	0·382	0·098	0·0656	15·25	14·16	−7·15
MC·5	0·385	0·139	0·0920	10·87	10·74	−1·19
E.5	0·389	0·091	0·0641	15·59	15·08	−3·27
W^{1}4	0·406	0·071	0·0554	18·04	18·36	+1·77
W^{1}3	0·416	0·076	0·0571	17·51	17·65	+0·80
W^{1}5	0·423	0·068	0·0504	19·86	19·20	−3·32
W^{1}6	0·428	0·071	0·0537	18·61	18·71	+0·54
E.1	0·451	0·075	0·0477	20·97	18·36	−12·45

Application of the Formula to Fabrics other than All-Wool Fabrics

The same formula can be used to compare fabrics composed of materials other than wool with all-wool fabrics of equal weight and thickness, and in this way unequivocal comparison of the several textile fibres as heat insulators can be made; for the total heat loss of a given fabric can be determined experimentally, and the total heat loss of a theoretical fabric of identical structure, but composed of wool, may be calculated. Calculations of this kind have been carried out in the case of all the non-wool fabrics examined, and the values so obtained are given in column 5 of Table XVIII. The difference between actual and calculated heat loss is in each case given in column 6. For woven cotton fabrics, the mean deviation is 23·6%, i.e. wool fabrics are 23·6% more efficient as heat insulators than cotton fabrics of identical thickness and weight. For knitted fabrics the difference appears to be greater, the mean deviation being 32·1% for the three samples tested. Of the four real silk fabrics examined, three show an approximately constant deviation of 23%, while the fourth, a knitted sample, has a deviation of only 11 per cent. Artificial silk fabrics also show a variable deviation, while the mixture fabrics show deviations between the zero of wool and the 23·6% average of the cellulose fabrics. In all cases wool fabrics appear to be definitely superior as heat insulators to those composed of other fibres.

Table XVIII

	Fabric No.	Density g./cc.	Thickness cm.	Heat Loss (exptl.) Cals/Sec/ sq cm.	Heat Loss (calc. for same Structure in Wool) Cals/Sec/ sq. cm.	% Error	Comments
A—Cotton	C.1	0·260	0·068	$21{\cdot}86\times10^{-3}$	$16{\cdot}90\times10^{-3}$	−22·42	Pique 11 ribs per inch
	C·2	0·363	0·048	31·30	23·08	−26·26	Pique 20 ribs per inch
	C.3	0·341	0·043	29·94	24·35	−18·66	Winceyette (fluffy material)
	C.4	0·555	0·023	49·19	38·07	−22·60	Fine rib structure
	C.5	0·6575	0·018	55·09	43·76	−20·56	Normal structure
	F.1A	0·5043	0·043	33·87	27·33	−19·32	Washed cotton suiting
	F.1	0·5672	0·038	38·25	30·61	−19·97	Ditto unwashed
	F.2A	0·6955	0·030	51·34	37·46	−27·05	Washed drill (very hard fabric)
	F.2	0·6979	0·030	52·64	37·52	−28·73	Ditto unwashed
	F.3A	0·4809	0·029	46·43	32·98	−28·97	Zampa washed
	F.3	0·6151	0·023	51·01	39·41	−22·74	Zampa unwashed
	F.4A	0·3980	0·043	36·24	25·31	−30·15	Cretonne washed
	F.4	0·5007	0·036	40·91	30·01	−26·65	Cretonne unwashed
	F.5A	0·6022	0·023	54·38	39·11	−28·08	Sheeting unwashed
	F.5	0·7525	0·018	56·99	45·95	−19·36	Sheeting washed
	A.1	0·1972	0·098	16·04	12·18	−24·06	Gauze weave
	A.6	0·1853	0·081	19·68	14·03	−28·70	Gauze weave
	A.7	0·1725	0·076	18·78	14·60	−22·26	Gauze weave
	O·1	0·5285	0·021	48·05	38·86	−19·16	Mercerised—normal structure
	O.4	0·3616	0·054	25·66	21·37	−16·72	Flannelette (fluffy material)
	V.1	0·2177	0·088	19·45	13·48	−30·70	Knitted cotton underwear
	V.2	0·2294	0·066	24·75	16·89	−31·76	
	V.3	0·2634	0·073	24·31	16·08	−33·86	
B—Art. Silk	K.4	0·4989	0·029	47·23	33·35	−29·40	Viscose, knitted
	O.3	0·3698	0·026	43·49	32·58	−25·20	Viscose, hollow fibre
	O 9	0·3443	0·033	31·07	28·43	− 8·50	Open knit, acetate silk
	O.10	0·3942	0·029	37·57	31·32	−16·63	Knitted hose, acetate silk
	O.11	0·2517	0·044	23·09	22·64	−- 1·95	Gauze knit, acetate silk
	O.8	0·6748	0·018	60·77	44·13	−27·38	Normal structure, Cuprammonium Silk
	S.3	0·3909	0·054	23·21	21·85	− 5·86	Viscose, scribbled yarns
C—Real Silk	O·12	0·7494	0·011	67·74	51·17	−24·45	Bleached spun crepe
	O·13	0·6030	0·018	53·67	42·60	−20·62	Spun silk
	O.14	0·2847	0·101	16·93	12·74	−24·75	Heavy ribbed knit, from underwear
	O.15	0·3788	0·038	30·16	26·85	−10·97	Plain knit, from underwear
D-Linen	O·5	0·5685	0·029	44·91	34·84	−22·42	Plain weave coarse linen
E—Mixtures	A.2	0·1595	0·119	11·80	10·08	−14·57	Gauze weave, wool cotton
	A.3	0·1645	0·091	15·36	12·61	−17·90	Gauze weave, wool cotton
	A.4	0·1653	0·098	14·35	11·89	−17·14	Gauze weave, cotton art. silk
	A.5	0·2799	0·048	27·36	21·80	−20·32	Gauze weave, cotton art. silk
	S.1	0·4273	0·043	28·89	25·83	−10·59	Suiting, wool 33·1%, art. silk 66·9%
	S.2	0·4289	0·043	29·10	25·86	−11·14	Suiting, wool 27·8%. art. silk 72·2%
	V.4	0·2108	0·122	11·80	10·28	−12·88	Knitted, wool 41·78%, cotton 58·22%
	E.7	0·5461	0·068	25·20	21·39	−15·12	Suiting, wool, cotton

SUMMARY

(1) The relation between thermal conductivity and thickness has been determined for compressed pads of loose wool at two widely different densities.

(2) The relation between thermal conductivity and density at constant thickness has been determined for compressed wool, cotton, and viscose silk.

(3) The effect of various finishing processes on the thermal conductivity of wool fabrics has been determined.

(4) The specific conductivities of a wide range of wool, cotton, linen, silk, artificial silk, and mixture fabrics have been determined.

(5) It has been found possible to express the warmth of all-wool fabrics by means of a general equation involving only measurements of their thickness and density.

(6) By the use of this equation, unequivocal comparison of the several textile fibres as heat insulators has been made.

Acknowledgment—The authors wish to express their indebtedness to Messrs. Wolsey Ltd., of Leicester, and to Mr. Stanley Wilson for grants which defrayed part of the expenses incurred by this investigation. Mr. Chamberlain wishes also to acknowledge the receipt of assistance from the Department of Scientific and Industrial Research, which allowed him to take part in the research. In addition, we wish to express our indebtedness to the following organisations for the supply of samples of fabrics used in the research—Messrs. Wolsey Ltd., The Cellular Clothing Co., Ben Musgrave (Bradford) Ltd., Vedonis Ltd., Messrs. Tootal, Broadhurst, Lee & Co., Peter Scott & Co. Ltd., and to the British Silk Research Association.

APPENDIX

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Fundamental Constants Used in Calculation

Latent heat of fusion of ice = 79·51 cals. per gram
Density of mercury at 20° C. = 13·5462 g./cc.
* Density of ice at 0° C. = 0·9168 g./cc.
* Density of water at 0° C = 0·99987 g./cc.

* These figures are mean values obtained from the results of several independent investigators.

TABLE OF CLOTH PARTICULARS

The following table contains all the available technical data with regard to the fabrics used. It is complete as regards the fabrics manufactured in the University, and as complete as it has been possible to make it with regard to the remainder.

COMPLETE LIST OF PARTICULARS OF ALL FABRICS EXAMINED

(1) Woven Fabrics

Series	No.	Wt. per yd. (56" wide) ozs.	Weave	Ends per Inch	Picks per Inch	Warp Counts	Warp Twist 2/fold	Warp Twist Single	Weft Counts	Weft Twist 2/fold	Weft Twist Single	Finishing Particulars
W¹	1	12·53	2/2 twill	128	73	2/60's worsted	20	25	2/60's worsted	20	25	Scoured only
	2	14·42	4/4 twill	140	84	2/60's ,,	20	25	2/60's ,,	20	25	,, ,,
	3	14·50	2/2 twilled hopsack	142	83	2/60's ,,	20	25	2/60's ,,	20	25	,, ,,
	4	13·21	2/2 hopsack	128	75	2/60's ,,	20	25	2/60's ,,	20	25	,, ,,
	5	13·18	Broken crow	133	74	2/60's ,,	20	25	2/60's ,,	20	25	,, ,,
	6	13·96	3/1 Rep	130	90	2/60's ,,	20	25	2/60's ,,	20	25	,, ,,
	7	12·75	3/1 twill	128	65	2/60's ,,	20	25	2/60's ,,	20	25	,, ,,
W²	1	30·41	Honeycomb	44	28	12 sk. woollen	—	9	12 silk woollen	—	9	,, ,,
	2	34·46	4/4 warp rib	44	38	12 ,, ,,	—	9	12 ,, ,,	—	9	Milled 45·90%
	3	29·86	4/4 hopsack	44	36	12 ,, ,,	—	9	12 ,, ,,	—	9	,, 32·14%
	4	23·98	Plain	39	33	12 ,, ,,	—	9	12 ,, ,,	—	9	,, 29·20%
	5	31·95	3/1 twill	44	39	12 ,, ,,	—	9	12 ,, ,,	—	9	,, 40·46%
	6	34·26	Reversible weft cord	44	38	12 ,, ,,	—	9	12 ,, ,,	—	9	,, 37·06%
M¹	1	18·67	3/3 twill	78	63	2/28's worsted	11	15	2/28's worsted	11	15	Scoured only, unmilled
	2	22·60	3/3 ,,	87	72	2/28's ,,	11	15	2/28's ,,	11	15	Milled 19·77%
	3	25·97	3/3 ,,	94	78	2/28's ,,	11	15	2/28's ,,	11	15	,, 32·43%
	4	27·03	3/3 ,,	96	75	2/28's ,,	11	15	2/28's ,,	11	15	,, 31·94%
	5	31·20	3/3 ,,	105	81	2/28's ,,	11	15	2/28's ,,	11	15	,, 44·06%
	6	20·05	3/3 ,,	81	70	2/28's ,,	11	15	2/28's ,,	11	15	,, 12·31%
	7	29·05	3/3 ,,	104	80	2/28's ,,	11	15	2/28's ,,	11	15	,, 41·34%
	8	19·14	3/3 ,,	80	66	2/28's ,,	11	15	2/28's ,,	11	15	,, 7·90%
	9	19·97	3/3 ,,	83	67	2/28's ,,	11	15	2/28's ,,	11	15	,, 11·79%
M²	1	19·88	3/3 ,,	74	72	2/28's ,,	11	15	2/28's ,,	11	15	,, 7·48%
	2	19·86	3/3 ,,	75	74	2/28's ,,	11	15	2/28's ,,	11	15	,, 11·85%
	3	21·31	3/3 ,,	78	78	2/28's ,,	11	15	2/28's ,,	11	15	,, 19·61%
	4	23·91	3/3 ,,	82	82	2/28's ,,	11	15	2/28's ,,	11	15	,, 27·05%
	5	29·56	3/3 ,,	91	90	2/28's ,,	11	15	2/28's ,,	11	15	,, 40·61%
	6	26·85	3/3 ,,	88	87	2/28's ,,	11	15	2/28's ,,	11	15	,, 34·60%
	7	25·63	3/3 ,,	84	85	2/28's ,,	11	15	2/28's ,,	11	15	,, 30·65%
	8	18·42	3/3 ,,	78	63	2/28's ,,	11	15	2/28's ,,	11	15	Scoured only, unmilled
R	1	25·42	3/3 ,,	93	86	2/28's ,,	11	15	2/28's ,,	11	15	Milled 30%, raised 1 round
	2	25·13	3/3 ,,	93	86	2/28's ,,	11	15	2/28's ,,	11	15	,, 30%, ,, 2 ,,
	3	25·00	3/3 ,,	93	86	2/28's ,,	11	15	2/28's ,,	11	15	,, 30%, ,, 4 ,,
	4	25·02	3/3 ,,	93	86	2/28's ,,	11	15	2/28's ,,	11	15	,, 30%, ,, 6 ,,
	5	25·55	3/3 ,,	93	86	2/28's ,,	11	15	2/28's ,,	11	15	,, 30%, unraised
	6	24·74	3/3 ,,	93	86	2/28's ,,	11	15	2/28's ,,	11	15	,, 30%, raised 8 round

	7	25·00	3/3 ,,	93	86	2/28's ,,	11	15	2/28's ,,	11	15	,, 30%, ,, 11 ,,
	8	25·13	3/3 ,,	93	86	2/28's ,,	11	15	2/28's ,,	11	15	,, 30%, ,, 15 ,,
	9	24·47	3/3 ,,	93	86	2/28's ,,	11	15	2/28's ,,	11	15	,, 30%, ,, 20 ,,
	10	23·67	3/3 ,,	93	86	2/28's ,,	11	15	2/28's ,,	11	15	,, 30%, ,, 20 ,, cut close
MC	1	17·95	3/3 ,,	74	72	2/28's ,,	11	15	2/28's ,,	11	15	,, 7·48%, cut close face and back
	2	18·99	3/3 ,,	75	74	2/28's ,,	11	15	2/28's ,,	11	15	,, 11·85%, ,, ,,
	3	19·92	3/3 ,,	78	78	2/28's ,,	11	15	2/28's ,,	11	15	,, 19·61%, ,, ,,
	4	21·45	3/3 ,,	82	82	2/28's ,,	11	15	2/28's ,,	11	15	,, 27·05%, ,, ,,
	5	24·56	3/3 ,,	91	90	2/28's ,,	11	15	2/28's ,,	11	15	,, 40·61%, ,, ,,
	6	22·97	3/3 ,,	88	87	2/28's ,,	11	15	2/28's ,,	11	15	,, 34·60%, ,, ,,
	7	21·85	3/3 ,,	84	85	2/28's ,,	11	15	2/28's ,,	11	15	,, 30·65%, ,, ,,
	8	17·16	3/3 ,,	78	63	2/28's ,,	11	15	2/28's ,,	11	15	Scoured only
B	1	19·12	2/2 ,,	—	—	—	—	—	—	—	—	Milled and raised to extent unknown
	3	18·29	2/2 ,,	—	—	—	—	—	—	—	—	,, ,, ,,
	2	19·68	2/2 ,,	—	—	—	—	—	—	—	—	,, ,, ,,
E	1	15·52	Plain	43	37	2/20's worsted	10	18	2/20's worsted	10	18	Scoured only
	2	13·35	,,	42	26	2/20's ,,	10	12	2/20's ,,	10	12	,, ,,
	3	36·5	2/2 twill	—	—	—	—	—	—	—	—	Very heavily milled, exact extent unknown
	4	8·33	Crepe	40	37	18's worsted	—	13	18's worsted	—	15	Scoured only
	5	16·25	Probably broken twill	—	—	—	—	—	—	—	—	Doeskin (dress-face) finish. Black dye
	7	17·03	Warp backed 2/2 twill	54 face 51 back	64	—	—	—	—	—	—	
A	1	8·87	Gauze	32	50	—	—	—	—	—	—	Scoured only
	2	8·71	,,	22	40	—	—	—	—	—	—	Scoured only (44·3% cotton, 55·7% wool)
	3	6·87	,,	38	42	—	—	—	—	—	—	Scoured only (45·7% cotton, 54·3% wool)
	4	7·43	,,	42	32	—	—	—	—	—	—	Scoured only
	5	6·16	,,	70	51	—	—	—	—	—	—	,, ,,
	6	6·88	,,	50	50	—	—	—	—	—	—	,, ,,
	7	6·01	,,	35	45	—	—	—	—	—	—	,, ,,
C	1	8·12	Pique, 11 ribs per inch	110 ground	100	45's cotton ground	—	27	38's cotton	—	25	As finished by makers, particulars unknown
				22 wadding	—	10's cotton wadding	—	9				
	2	7·99	Pique, 20 ribs per inch	120 ground	96	45's cotton ground	—	25	38's cotton	—	20	As finished by makers, particulars unknown
				20 wadding	—	2/32's cotton wadding	—	23	—		—	
	3	6·73	2/2 twill	70	61	—	—	—	—	—	—	As finished by makers, (surface napped)
	4	5·85	2/1 warp rib	83	80	—	—	—	—	—	—	As finished by makers
	5	5·43	Plain	77	77	—	—	—	—	—	—	,, ,,
F	1	9·89	Warp and weft rib pattern	104	83	21's cotton	—	16	21's cotton	—	19	,, ,,
	1A	9·95	Warp and weft rib pattern	104	83	21's ,,	—	16	21's ,,	—	19	As F.1, but scoured in soft soap
	2	9·60	2/1 turned twill	120	74	28's ,,	—	20	23's ,,	—	16	As finished by makers

Complete List of Particulars of all Fabrics Examined. (1) Woven Fabrics—*continued*

Series	No.	Wt. per yd. (56″ wide) ozs.	Weave	Ends per Inch	Picks per Inch	Warp Counts	Warp Twist 2/fold	Warp Twist Single	Weft Counts	Weft Twist 2/fold	Weft Twist Single	Finishing Particulars
	2A	9·57	2/1 turned twill	120	74	28's cotton	—	20	23's cotton	—	16	As F 2, but scoured in soft soap
	3	6·49	Plain	52	42	18's ,,	—	15	15's ,,	—	15	As finished by makers
	3A	6·40	,,	52	42	18's ,,	—	15	15's ,,	—	15	As F.3, but scoured in soft soap
	4	8·27	,,	38	38	11's ,,	—	14	11's ,,	—	14	As finished by makers
	4A	7·85	,,	38	38	11's ,,	—	14	11's ,,	—	14	As F.4, but scoured in soft soap
	5	6·21	,,	70	67	28's ,,	—	20	25's ,,	—	18	As finished by makers
	5A	6·35	,,	70	67	28's ,,	—	20	25's ,,	—	18	As F.5, but scoured in soft soap
O	1	5·09	5-end sateen	—	—	—	—	—	—	—	—	Unknown, apart from mercerisation
	4	8·96	Plain	—	—	—	—	—	—	—	—	Surface napped
	5	7·56	,,	—	—	—	—	—	—	—	—	Scoured only (linen)
	8	5·57	,,	—	—	—	—	—	—	—	—	As finished by makers. Washed in running water
	12	3·78	,,	—	—	—	—	—	—	—	—	Unknown apart from bleaching
	13	4·98	,,	—	—	—	—	—	—	—	—	Unknown
S	1	8·43	2/2 twill	—	—	—	—	—	—	—	—	33% wool, 67% viscose
	2	8·46	Plain	—	—	—	—	—	—	—	—	28% wool, 72% viscose
	3	9·68	2/2 twill	—	—	—	—	—	—	—	—	100% viscose, scribbled yarns

(2) Knitted Fabrics

Series	No.	Details of Structure	Loops per Inch	Material	Weight per Yard (56″ wide)	Series	No	Details of Structure	Loops per Inch	Material	Weight per Yard (56″ wide)
K	1	Normal	21	Fine crossbred	11·80	P	1	Normal	19	All wool	6·58
	2	,,	32	,, ,,	7·73		2	,,	21	,,	7·61
	3	,,	26	,, ,,	9·75		3	,,	18	,,	13·02
	4	,,	37	Viscose	6·64		4	,,	29	,,	8·46
	5	,,	21	Medium crossbred	12·38	V	1	2-thread structure	29	All cotton	8·79
	6	,,	29	,,	8·69		2	,, ,,	35	,,	6·94
	7	,,	26	Fine crossbred	10·59		3	,, ,,	22	,,	8·82
	8	,,	29	,, ,,	8·06		4	,, ,,	22	Cotton and wool	11·80
	9	,,	21	,, ,,	12·94	O	3	Normal	45	Hollow-fibre viscose	4·41
	10	,,	30	Dry spun Botany	8·18		9	Open knit	29	Acetate silk	5·21
	11	,,	26	,, ,,	11·13		10	Normal	51	,, ,,	5·24
	12	,,	19	,, ,,	11·39		11	Very open gauze	Circ. 12	,, ,,	5·08
							14	Heavy ribbed structure	50	Real silk	13·19
							15	Normal	22	,, ,,	6·60

4—THE ABSORPTION, TRANSMISSION, AND REFLECTION OF RADIANT HEAT BY FABRICS

By JAMES GREGORY, B.Sc.
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I—INTRODUCTION AND SUMMARY

The problem of maintaining the body at normal temperature under conditions of tropical heat is one of thermal equilibrium. In addition to the heat generated by the natural processes of the body, a considerable amount of heat is received from the sun directly or through the medium of the clothes. If the temperature of the body is to remain normal, an amount of heat must be dissipated equal to that engendered by the above causes. The amount of heat received by the body from the sun must be as small as possible, and consequently a fabric possessing a high reflecting power for radiant energy is required. Since the clothes lose heat by the emission of radiation and by contact with cooler air, as much as possible of the heat from the sun remaining after reflection should be absorbed by the clothes. If the condition of the air as regards rate of movement or temperature is insufficient to cause the required heat loss, cooling can only be obtained by the evaporation of moisture generated by perspiration. This evaporation must be obstructed as little as possible, and takes place through the medium of the clothes, or may be brought about by suitable arrangement of a loose garment, which provides a bellows action through the movement of the body.

The requirements of a fabric in order that it may provide suitable clothing under tropical conditions of heat can therefore be summarised as follows—high reflecting and emissive powers, low transmitting power for radiant energy and in addition, high permeability to moisture.

Continuing previous work on this problem (*Shirley Inst. Mem.*, 1926, **5**, 193; or *J. Text. Inst.*, 1926, **17**, T553), the present account describes methods developed for the measurement of the absorption, transmission and reflection of radiant heat by fabrics. No standard method was available which could be applied to material in the form of fabric, but the methods now described are simple in theory, although, in common with other thermal measurements, they require considerable time for operation. It has not been found practicable to measure the factors of absorption, transmission and reflection of radiant heat separately, but these quantities are obtained indirectly from measurements of two combinations of the absorption and transmission factors. The symbols employed are—

A=% of incident radiant heat which is absorbed by the fabric.
T=% of incident radiant heat which is transmitted by the fabric.
R=% of incident radiant heat which is reflected by the fabric.

By definition, $A+T+R=100$.

Using the methods described, twenty-one cotton fabrics have been tested, the majority being typical of those exported to the tropics, and also five artificial silk or artificial silk and cotton union fabrics. The tests on the latter are included as being of general interest, and to show whether any improvement could be effected by the introduction of artificial silk into fabrics for tropical use. Considering for the moment the series of cotton fabrics, the range of variation of the factors encountered is as follows—

I—*Reflecting Power*—from 61% for a sateen and an acid-treated drill (described in Table I, p. T64) to 39% for a light unfilled plain woven fabric.

II—*Transmitting Power*—from 5% for a sateen to 44% for a light unfilled plain woven fabric.

III—*Absorptive Power*—from 34% for a sateen, a duck, and a filled fabric to 17% for a light unfilled plain woven fabric.

It is noteworthy that as much as 60% of the sun's heat may be reflected directly by the wearing of a closely woven and impenetrable fabric. With increasing weight, the absorption and reflection factors increase, the highest reflection factor resulting from a smooth, closely woven fabric such as a sateen or an acid-treated drill. A figure obtained for the reflecting power of the material $R/(100\text{-}T)$ varies little over the whole range of cotton fabrics tested, but the reflecting power of the artificial silk fabrics is decidedly lower. No advantage can therefore be gained by incorporating artificial silk into fabrics from the point of view of increased reflection of radiant heat. The range of variation between different fabrics is greatest for heat transmission and least for reflection. Certain heavily filled fabrics show high reflecting powers, but this power will be considerably reduced on removal of the filling material.

A criterion of unsuitability of fabrics is the value of $\frac{1}{2}A+T$, this referring to garments not in contact with the skin. For garments in contact with the skin the criterion of unsuitability is the value of $A+T$, and in general a measure of unsuitability is given by T plus a fraction of A varying between one-half and unity.

The position of the fabric C (weft sateen; see Table I, p. T64) is very marked in the table of relative values of $\frac{1}{2}A+T$, indicating that of all the fabrics tested, this is most suitable from the point of view of protection from the sun's heat. Next come the fabrics A (duck) and B (acid-treated drill), which are in turn followed by the heavily filled fabrics F, H and K, which afford a high degree of protection in proportion to their weight. Of the remaining fabrics, E and I (drills) and N (twill) are the best, but the unsuitability of the ramie fibre fabrics J and L is marked, this being due most probably to the open type of weave of these fabrics.

On theoretical grounds the emissive powers of fabrics cannot be expected to vary to any great extent, and this is supported by a few actual tests in which a variation of not more than 13% was obtained, the fabrics including one which was lamp-blacked.

In considering the choice of fabrics for tropical wear, the factor of permeability to moisture is of prime importance. A resumé will therefore be given of the general conclusions arrived at regarding the means of transfer of moisture through fabrics, described in the succeeding publication—(*a*) when conditions are such that moisture transfer takes place by diffusion through a layer of air enclosed between the fabric and the body, there is little to choose between fabrics, whatever their construction may be; (*b*) it is debatable whether the ventilation afforded by a fabric which is permeable to air is more effective than the alternative method of ventilation due to the bellows action of a non-permeable garment provided with suitable vents; (*c*) under conditions where a fabric is in contact with a moist surface and is fanned by a breeze, the rate of moisture transfer is dependent on the structure of the fabric (a sateen fabric possesses a small resistance compared with fabrics such as duck and acid-treated drill of the same order of weight).

It has been seen that the fabric C (sateen) is preferable to the others for its heat protecting qualities. In view of the above conclusions regarding moisture transfer, the sateen type of weave appears to offer advantages for wear under tropical conditions, over other types of weave, for equal weights of the resultant fabrics.

II—EXPERIMENTAL

(1) The Determination of the Absorption, Transmission and Reflection of Radiant Heat by Fabrics

(*a*) *Measurement of* $\frac{1}{2}A+T$. A fabric supported a short distance from the heat measuring surface A (Fig. 1) receives heat through an aperture E, the heat absorbed by the fabric causing its temperature to rise so that the receiver registers the transmitted heat and in addition some heat re-radiated by the fabric. In a state of equilibrium all the heat absorbed by the fabric is re-radiated, and since the emission is the same from both fabric surfaces, one-half the absorbed heat is radiated from the lower fabric surface. The receiver top is so arranged that the fabric plane passes through the rim of the vessel, the fabric resting by means of its own weight on extremely fine cross wires. The receiver therefore measures the sum of the transmitted heat and one-half of the absorbed heat, i.e. $\frac{1}{2}A+T$, the effect being independent of the direction or distribution of the heat leaving the lower fabric surface.

(*b*) *Measurement of* $A+T$. The fabric is placed in close contact with the top of a second receiver A′ (Fig. 1), which has a plane absorbing surface. The transmitted heat, together with the heat absorbed by the fabric, is received by the heat measuring surface, the transmitted heat directly and the absorbed heat by conduction. The outer surface of the fabric does not rise appreciably in temperature over its surroundings, heat loss by radiation therefore being negligible.

Knowing $\frac{1}{2}A+T$ and $A+T$ for any specimen of fabric, $A=2[(A+T)-(\frac{1}{2}A+T)]$, $T=2(\frac{1}{2}A+T)-(A+T)$, $R=100-(A+T)$.

(2) The Source of Heat Employed in Testing

The ideal source of heat for testing would be that under which fabrics are used in service. The radiation from the sun varies, however, both in quality and in intensity, so that its use for testing is impracticable. The source of heat employed in obtaining the present results consists of a 500 watt tungsten filament gas-filled lamp, the current being supplied by a storage battery. The distribution of energy from the lamp is that due to radiation from a body at a temperature much lower than that of the sun, consequently the maximum in the curve of energy distribution occurs in a region of much greater wave-length than in the case of the sun. The filament of the lamp, however, is enclosed in a glass bulb which absorbs the longer wave-lengths, becoming heated in the process. An idea of the proportion of heat emitted by the filament which is transmitted unchanged through the glass and received by the fabric, was obtained as a result of a subsidiary determination in which the normal receiver A or A′ was replaced by a quick registering thermopile. On switching off the current through the filament (the filament cools with enormous rapidity compared with the glass bulb and the heated surroundings, which have a larger heat capacity and lower temperature than the filament) the heat registered by the thermopile is approximately one-eighth of that previously received, i.e., approximately seven-eighths of the heat radiated from the filament and received by the

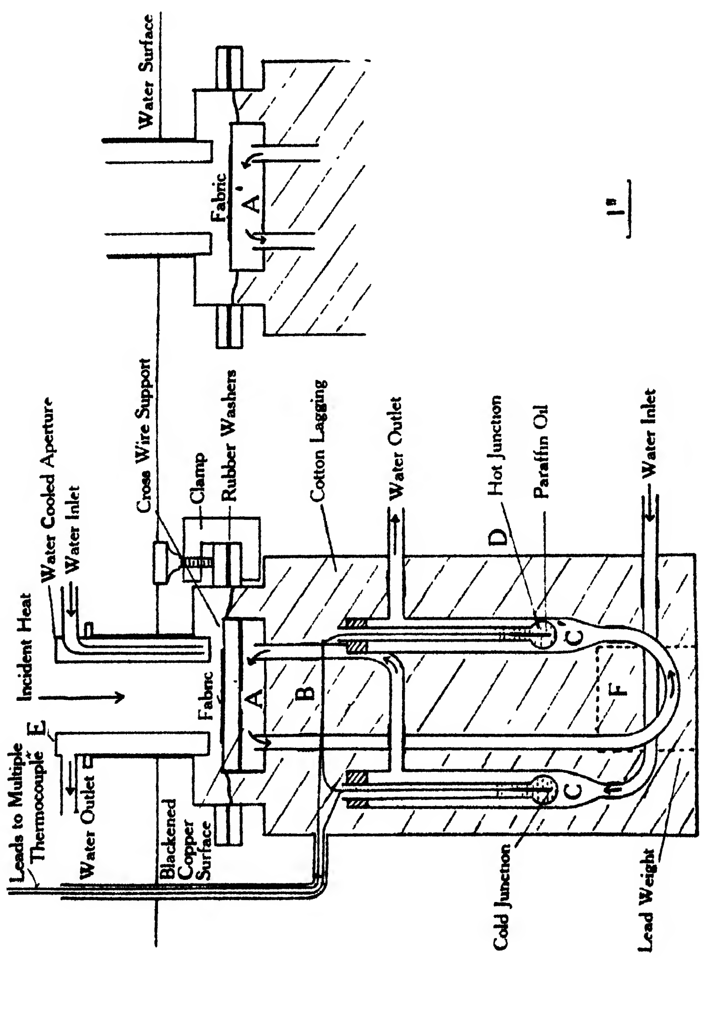
Leads to Multiple Thermocouple
E
Water Outlet
Incident Heat
Water Cooled Aperture
Water Inlet
Cross Wire Support
Clamp
Rubber Washers
Cotton Lagging
Water Outlet
D
Hot Junction
Paraffin Oil
Water Inlet
Blackened Copper Surface
Fabric
A
B
C'
C
F
Cold Junction
Lead Weight
Water Surface
Fabric
A'
1"

FIG. 1

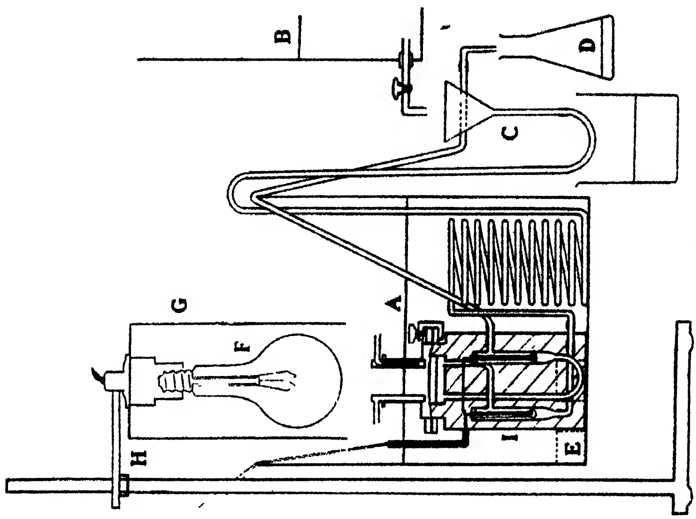
B
D
C
G
F
A
H
I
E

FIG. 2

fabric is transmitted unchanged through the glass. Now the energy received at the earth's surface from the sun is roughly such as would be transmitted by the average type of glass (due to absorption of longer heat waves by the atmosphere), and it is therefore concluded that, as far as the testing of white fabrics is concerned, the results obtained, using the present source of heat, give values for the absorption, transmission and reflection factors that afford a useful means of comparison of fabrics under conditions of service. The effect of increasing the proportion of long heat waves in the source of heat used for testing would be to reduce the amount of heat reflected, since long heat waves emitted by bodies at comparatively low temperatures are easily absorbed. This was confirmed by a test employing a blackened copper surface maintained at a temperature of 100° C. as source of heat in place of the gas-filled lamp. A reduction was then caused in the reflection factor from a normal 61 per cent. down to 7 per cent. It is probable that the reflection factors determined under the conditions of experiment are too low, owing to the proportion of one-eighth of the heat incident on the fabric being of long wave-length, and therefore readily absorbed by the fabric.

(3) Constant-flow Water Calorimeter Measuring Device

The heat measuring device to which reference has been made consists of a cylindrical copper vessel through which a steady flow of water at constant temperature is maintained. In a state of equilibrium the heat received by the surface of the receiver is conducted to the water, the rise in temperature of which is measured by means of differential thermocouples, B (Fig. 1). These consist of 10 couples of copper and constantan in series, alternate junctions being at the same temperature. The cold and hot junctions dip into paraffin oil contained in glass bulbs CC′ (Fig. 1), surrounded by the water flow before and after passage through the receiver.

The amount of heat received (expressed in calories per sec.) is the product of the rate of flow of water (gms. per sec.), the rise in temperature (°C.) of the water flow, and the specific heat of water (=1 to a sufficient approximation).

(4) Manipulative Details

In order to eliminate stray heating or cooling effects, the copper receiver, thermocouple containers, connecting tubes, etc., are lagged with cotton sliver and housed in a metal box, D (Fig. 1), placed under water in a constant temperature bath, A (Fig. 2). The bath, which is thermostatically controlled, is used to maintain the water flow at constant temperature, 20° C., the water passing through a copper coil (25 feet of ¼-inch diameter tube) immersed in the bath.

A constant rate of flow of water is attained by employing a fixed head of water of about two inches. Owing to the presence of dissolved air in tap water causing a decrease in rate of flow, water free from air must be used. Distilled water contained in a large bottle, B (Fig. 2), is allowed to drip into a glass funnel, C (Fig. 2), the excess water flowing over the rim. The rate of flow is determined by collecting in a conical flask, D (Fig. 2), the water run through the apparatus over a period of five minutes. The rate of flow determines the temperature difference to be observed for a given amount of heat received and it is necessary that whilst this temperature difference should be sufficiently large to measure with reasonable accuracy, the actual temperature rise must be small. The use of multiple thermojunctions fulfils these requirements, a rise in temperature of 1° C. corresponding to an electro-

motive force of 400 micro-volts. The greatest amount of heat received developed an electromotive force of 200 micro-volts, which corresponds to a temperature rise of 0·5° C. The potentiometer, by means of which the electromotive force is measured, may be read to 0·5 micro-volt. Any variation in water flow rate or temperature may cause error due to the considerable thermal lag possessed by the measuring device, and it is therefore necessary to ensure good working of the thermostat and to employ efficient stirring of the bath water.

In both measurements of $\frac{1}{2}A+T$ and $A+T$ the heat received in the absence of the fabric is determined, this being independent of the type of receiver employed. It is not necessary to calibrate the thermocouple used for temperature measurement, since $\frac{1}{2}A+T$ and $A+T$ are expressed as percentages of incident heat, electromotive force being directly proportional to temperature over the small range of temperature encountered. The voltage across the lamp leads is measured by a potentiometer, being maintained constant at 35 volts by means of a rheostat in series with the lamp. The lamp is contained in a lamphouse, G (Fig. 2), which can be placed in the required position by means of a stop, H (Fig. 2). It is necessary that the box, I (Fig. 2) shall always be in the same position relative to the lamp, and this is effected by the use of stops consisting of lead weights, E (Fig. 2). The heat received from the source is measured once daily, whilst the rheostat is adjusted at frequent intervals. A water-cooled lampblacked aperture, E (Fig. 1), gives protection against stray sources of heat and limits the beam of radiation which is incident normally on the fabric. If the radiant heat is incident direct on the measuring surface, as in the $\frac{1}{2}A+T$ determination, the surface is covered with lampblack by holding over burning camphor, and the whole of the radiation is absorbed. The heat may be incident on the fabric when in contact with the receiver, as in the $A+T$ determination, in which case the receiver is blackened with a good dead-black paint, and the fabric is laid without tension on a thin film of seccotine. The reflection factor of the paint and seccotine film is very low (approximately 6%), so that heat loss due to reflection from the background, which is limited owing to absorption by the fabric, is very small.

It is necessary at various stages to interrupt the thermal equilibrium of the apparatus; for example, to replace a fabric sample or to lampblack the receiver surface. To replace a fabric in the $\frac{1}{2}A+T$ determination it is only necessary to remove the water-cooled aperture, which makes a sliding fit, but in the $A+T$ determination the whole apparatus must be removed from the water and the top taken off. This is normally held by three clamps with an insulation of rubber. The fabric is wetted so as not to injure the black paint surface on removal. For these reasons a shorter equilibrium period can be used for the $\frac{1}{2}A+T$ determination (20 minutes) than for the $A+T$ determination (30 minutes). When the $A+T$ receiver is coated with lamp black it is necessary to remove the cotton lagging, a considerable heating effect taking place. After such operations the rate of flow of water may be temporarily increased to hasten equilibrium. A lead weight, F (Fig. 1), is placed in the box so that the apparatus will maintain its position under water by its own weight.

The water-cooled aperture which closes the top of the box takes its temperature from a separate water flow system, the water flow at the same time providing the necessary cooling agent for the thermostatic control of

the bath. The inside walls and bottom of the aperture, and also the exposed walls surrounding the receiver, are lampblacked.

(5) A Check on the Working of the Apparatus

If in the $\frac{1}{2}A+T$ determination the fabric is replaced by an opaque disc of material which is lampblacked on both sides, since $R=T=O$ and $A=100\%$, then $\frac{1}{2}A+T=50\%$. This test has been applied with the following results—

Copper foil—low heat capacity, $\frac{1}{2}A+T=50{\cdot}2$ per cent.

Heavy copper disc—large heat capacity, $\frac{1}{2}A+T=49{\cdot}5$ per cent.

Closely woven fabric, $\frac{1}{2}A+T=49{\cdot}8$ per cent.

(6) Procedure for Testing Fabrics and Sampling

In the determination of $A+T$ the fabric is stuck down and has to be wetted before it can be removed. The specimen is therefore useless for further tests, and so the determination of $\frac{1}{2}A+T$ is made first. It is usual to test a batch of samples for $\frac{1}{2}A+T$, and then after changing the receiver to test for $A+T$. Previous to testing, the fabrics are dried in a desiccator containing phosphorus pentoxide. The samples are $1\frac{7}{8}$ inch in diameter, the actual diameter tested being $1\frac{5}{8}$ inch. Six samples are chosen at random from a two-yard length of the fabric.

III—DISCUSSION OF RESULTS

In connection with tests on finished fabrics it is almost impossible to obtain full data regarding details of finish, counts of yarn, etc., owing to the number of hands through which the fabrics have passed during manufacture. Most of the fabrics tested have been supplied as typical of those exported to the tropics, and were with one exception bleached. Twenty-one fabrics have been examined and the results tabulated in Table I, where details are also given of the type of weave, number of ends and picks per inch, finish, market and weight. The fabrics are arranged in order of decreasing weights, as this is the chief and most independent variable.

The range of variation of the factors is—

I—*Reflection*—From 61% for C (sateen) and B (acid-treated drill) to 39% for U (light unfilled plain woven fabric).

II—*Absorption*—From 34% for C, A (duck) and H (filled fabric) to 17% for U.

III—*Transmission*—From 5% for C to 44% for U.

The range of variation is thus greatest for the transmission factor and least for the reflection factor. In a general way, with increasing weight, the factors of absorption and reflection increase whilst the transmission factor decreases. With respect to the correlation of the reflection and transmission factors, it may be pointed out that $R/(100-T)$ varies very little throughout the range (Table I). If we regard T as measuring the holes in the fabric, then $(100-T)$ measures the area of actual material and $R/(100-T)$ the reflecting power of the material (equals 1 for a perfect reflector).

A supplementary series of five artificial silks, and artificial silk and cotton union fabrics was tested and the results are given in Table II. The values for $R/(100-T)$ in this table are distinctly lower than for cotton fabrics, indicating that the artificial silks have a lower reflecting power. There appears to be no advantage gained by the inclusion of artificial silk with cotton from the point of view of reflection of heat by fabrics.

A general conclusion that a high reflection factor results from as close and smooth a surface as possible is arrived at by a study of the figures in

Table I. This is in accordance with what would naturally be expected; the more uneven a surface is, the less chance the reflected heat has of an unobstructed path away from the fabric. Both the fabrics C (sateen) and B (acid-treated drill) which show the highest reflecting power for the series have smooth, closely woven surfaces. The cellular woven fabric D, although nearly equal in weight to the sateen fabric C, has a much lower reflection factor. Of the filled fabrics (F, H, K, M, Q) the reflection factors for the first three, which are heavily filled, are high. This is attributable to the

Table I

Market	Weight in lb. per sq. yard	Ends per Inch	Picks per Inch	No. of Samples Tested	A%	T%	R%	$\left(\frac{R}{100-T}\right)$	$(\frac{1}{2}A+T)$ %	Fabric
—	0·52	96	64	4	34	10	56	0·62	27	A
—	0·44	110	60	6	27	12	61	0·69	26	B
—	0·37	66	250	6	34	5	61	0·64	22	C
—	0·31	—	—	6	27	24	49	0·64	38	D
India ...	0·30	108	48	6	24	18	57	0·70	30	E
Persia ...	0·30	68	72	6	21	20	59	0·74	30	F
—	0·30	98	58	6	23	24	53	0·70	36	G
China ...	0·29	80	88	6	34	11	55	0·62	28	H
India ...	0·28	84	57	6	28	17	55	0·66	31	I
China ...	0·27	47	55	6	22	34	44	0·67	45	J
India ...	0·24	76	78	6	25	19	56	0·69	31	K
China ...	0·21	44	46	6	20	37	43	0·70	47	L
S. America ...	0·20	76	88	6	25	27	47	0·64	40	M
India ...	0·19	80	110	6	26	21	52	0·66	34	N
India ...	0·19	76	88	5	25	24	51	0·67	36	O
S. America ...	0·19	76	88	6	29	23	48	0·62	38	P
Egypt ...	0·19	76	88	6	30	25	45	0·60	40	Q
—	0·19	78	77	6	20	32	48	0·71	42	R
—	0·15	96	97	4	21	33	46	0·69	43	S
—	0·12	119	131	4	22	36	42	0·66	47	T
—	0·08	112	117	4	17	44	39	0·70	53	U

A Duck.
B Acid-treated drill. A semi-parchmentised fabric, produced according to a patented process using strong sulphuric acid.
C Weft sateen.
D Cellular woven fabric.
E Drill. A little starch and calendered
F Plain weave. Back filled, china clay and starch. Calendered.
G Drill.
H Plain weave. Back filled, china clay and starch Calendered.
I Drill Calendered.
J Ramie fibre fabric. Unbleached. Plain weave.
K Plain weave Back filled, china clay and starch Calendered.
L Ramie fibre fabric. Bleached. Plain weave.
M Plain weave. Filled, starch, clay and Epsom salts Calendered.
N Twill. Calendered. Beetled.
O Plain weave. Beetled.
P Plain weave Slight running of starch. Beetled.
Q Plain weave. Filled, starch and clay Heavy calender.
R, S, T and U Plain weave. No filling.

degree of filling on the fabric, removal of which would result in a considerable decrease in reflecting power.

A column of figures is given in Tables I and II showing the values of $\frac{1}{2}A+T$ for the various fabrics. This value, which is a measure of the "hotness" or unsuitability of the fabric, is readily seen to be a minimum on making R a maximum and T a minimum. This figure only refers to garments not in contact with the skin. For garments in contact with the skin, the criterion

of unsuitability is the value of $A+T$, so that in general a measure of unsuitability is given by T plus a fraction of A varying between one half and unity.

The position of the fabric C (weft sateen) is very marked in the table of relative values of $\frac{1}{2}A+T$, indicating that of all the fabrics tested, this is most suitable from the point of view of protection in general against the sun's heat. Next in order come the fabric A (duck) and B (acid-treated drill), which are in turn followed by the heavily filled fabrics F, H and K, which in proportion to their weight afford a high degree of protection. Of the remaining fabrics, E and I (drills) and N (twill) are the best, but the unsuitability of the ramie fibre fabrics J and L is most marked, this being due most probably to the open type of weave of these fabrics.

Table II

Fabric	Description of Fabric	Surface Receiving Radiation	Weight in lb. per sq. yard	No. of Samples Tested	A%	T%	R%	$\left(\frac{R}{100-T}\right)$	$(\frac{1}{2}A+T)$ %
V	Celanese self-stripe knitted fabric Acetate silk	Both surfaces alike	0·23	4	23	40	37	0·62	52
W	Crêpe satin Woven fabric Viscose weft Cotton warp	Viscose weft	0·20	4	27	31	42	0·61	44
W	Ditto	Cotton warp	—	4	29	29	42	0·59	44
X	Woven fabric Acetate weft Viscose warp	Viscose warp	0·17	4	35	30	35	0·50	48
X	Ditto	Acetate weft	—	4	33	31	35	0·51	48
Y	Knitted fabric Hollow viscose yarn	Both surfaces alike	0·17	4	23	43	33	0·58	55
Z	"Ninon" Acetate silk Woven fabric	Both surfaces alike	0·06	3	6·5	78	15	0·67	81

Emissivity of Fabrics

On theoretical grounds the emissive powers of fabrics cannot be expected to vary to any great extent. A simple method for measuring the relative emissive powers of fabrics was employed, and consisted in fastening the fabric to a copper surface (6 inches square) maintained at a temperature of 100° C. by boiling water. The surface on which the fabric was laid down was polished, so that for a transparent fabric little heat would be radiated from the background through the interstices in the fabric. A thermopile suitably fitted with shield and water-cooled shutter maintained at a temperature of 20° C. was used to measure the heat radiated by the fabric. The results (Table III) show that there is little variation in emissive power between the different fabrics, which include one which was lamp-blacked. The maximum variation encountered is approximately 13 per cent.

Table III

E.M.F. Generated by Thermopile (millivolts); Corresponds to Heat Received.

Polished copper ...	26	Lamp-blacked fabric	285
A (duck)	299	C (sateen)	263
G (drill)	288	T (plain weave) ...	260
B (acid-treated drill)	286	U (plain weave) ...	260

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5—THE TRANSFER OF MOISTURE THROUGH FABRICS

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CONTENTS

INTRODUCTION AND SUMMARY

In connection with the work on thermal properties of fabrics described in the preceding communication, it was stated that, among other desiderata of fabrics used for clothing in the tropics, a high value of permeability to water vapour was essential. The present work was undertaken with the object of examining the means by which water vapour evaporated from the body reaches the outside atmosphere, and of determining the resistance opposed to this transfer of moisture by fabrics of varying construction.

A method of test simulating those conditions of moisture transfer in which a layer of air is enclosed between the fabric and the body, showed a surprisingly small variation in moisture transferring powers for fabrics of widely differing construction. In order to account for this result, an examination of the mechanism of the moisture transfer under the conditions of experiment was undertaken.

The passage of moisture from the liquid surface to the outside atmosphere may be divided into three stages—(*a*) between liquid surface and the underside of the fabric; (*b*) through the fabric; and (*c*) between the upper surface of the fabric and the free atmosphere which is in contact with it. The passage between the liquid surface and the underside of the fabric is by diffusion, whilst that between the upper surface of the fabric and the atmosphere is by diffusion assisted by convection to an amount depending on the degree of motion of the air. A determination of the concentrations of vapour at various stages in the moisture transfer (of which only the concentrations at the two fabric surfaces were unknown) revealed the fact that although the concentration gradient* for a single layer of fabric may vary by several hundred per cent. from one material to another, it is always small compared with the total concentration difference existing between the liquid surface and the outside atmosphere. This explains why fabrics differing widely in construction have rates of moisture transfer within a comparatively small range.

The mode of passage of vapour through the fabric was examined by constructing a series of fabrics of a material which does not absorb moisture, so that transmission must take place by diffusion only. Both the size of the individual apertures and their number could be varied in a known manner. The conclusion is drawn as a result of tests on this series of fabrics that the

* In connection with moisture vapour concentration, temperature and relative humidity, the term "gradient" has precisely the meaning associated with it in a term like "hill gradient"; it expresses the degree of change in these respective quantities with position.

passage of moisture through a fabric may be accounted for as taking place almost entirely by diffusion, and that the resistance opposed by the fabric is not dependent on the number and size of holes to any appreciable extent. The reasons for this state of affairs are (*a*) as the size of an individual aperture is decreased the flow through unit area of the aperture is accelerated; and (*b*) with many holes in a given area, the flow through any given hole is reduced by the interference of its neighbours, but when there are fewer holes they are obviously farther apart, the mutual interference is less, and each hole passes more vapour than before.

Actually, the layer of air between the fabric and the moist surface may not be enclosed. The conditions of wear may allow of relative motion between fabric and body, which results in displacement of air either through the fabric interstices or through vents in the clothing. This mode of transfer of moisture by which the air under the fabric is constantly desaturated by admixture with air from outside the fabric, is known as ventilation, and is concerned with the passage of moist air as a whole as distinct from passage by diffusion, which is, by comparison, a slower process. The ease of passage of air through a fabric is expressed by its factor of permeability, which is defined as the volume of air passing in unit time through unit area of fabric under unit pressure difference of the air on the two sides of the fabric.

Measurements of permeability to air on the series of fabrics employed in the tests for moisture transfer indicate a variation in this quantity between wide limits (in the ratio of 2,300 to 1). It is shown that, for fabrics of low permeability to air, the pressure difference generated between the two sides of a fabric by even small rates of movement is sufficient to overcome the forces tending to move the fabric relative to the body, so that little ventilation can take place through the fabric. It is obvious that for a fabric of low permeability, ventilation will take place through vents in the clothing, and such a fabric will exert by its movement a more efficient bellows action than a more open fabric. It is a debatable point whether a fabric of high permeability to air will allow of more efficient ventilation than a fabric of low permeability, but in general the former fabric may be preferred, since the air between fabric and body has a choice of passages to the outside air. Assuming that high permeability to air is desirable in a fabric, it is difficult to assess the minimum value of permeability for efficient ventilation beyond stating that a lower permeability factor is permissible for low rates of movement of fabrics in general, and for heavy or stiff fabrics as compared with light or limp fabrics. It is not possible to give any exact figure for this minimum value of permeability owing to the large variation in the forces controlling the stability of fabrics and owing to the dependence of this figure on the degree of motion of the fabric.

Arising out of the measurement of vapour concentration at various stages in the moisture transfer under conditions of test where a layer of air is enclosed between the fabric and the body, an expression was developed for the rate of moisture transfer in terms of partial coefficients of moisture transmission at the different stages. By suitable modification the expression could be applied to other sets of conditions more approximately realised in practice but difficult to simulate experimentally. The following sets of conditions were examined—(*a*) the effect of a moving stream of air over a fabric, (*b*) the effect of placing a fabric in contact with a moist surface, and (*c*) the effect of a moving stream of air over a fabric in contact with

a moist surface. The rates of moisture transference increase successively in the three groups of conditions, and ultimately in (*c*) the fabric resistance is the determining factor. A measure of the fabric resistance has been obtained by using a pile method of test developed in connection with some of the work on the determination of concentration differences. A range of variation of several hundred per cent. is shown to exist between extreme types of fabrics. In this connection an interesting result is noted, namely, that the resistance of a weft sateen to moisture transfer is low compared with fabrics such as a duck or an acid-treated drill, to which it is closely allied in weight. A probable explanation of this low resistance is put forward as a result of the conclusions arrived at regarding passage of moisture by diffusion through small holes, and is seen to be due to the slit type of formation of holes in a fabric of this weave. One other general effect of the increase in rate of transfer of moisture under any set of conditions is the extension of the range of variability between fabrics of different construction.

The general conclusions arrived at as a result of this work are—(*a*) when conditions are such that moisture transfer takes place by diffusion through a layer of air enclosed between the fabric and the body, there is little to choose between fabrics, whatever their construction may be; (*b*) it is debatable whether the ventilation afforded by a fabric which is permeable to air is more effective than the alternative method of ventilation due to the bellows action of a non-permeable garment provided with suitable vents; (*c*) under conditions where a fabric is in contact with a moist surface and is fanned by a breeze, the rate of moisture transfer is dependent on the structure of the fabric (a sateen fabric is seen to possess a small resistance compared with fabrics such as duck and acid-treated drill of the same order of weight).

Part I

A STANDARD METHOD OF TEST FOR THE TRANSFERENCE OF MOISTURE

(1) Description

The test conditions chosen are such as might occur in service. The atmosphere in contact with the clothed body has a temperature of approximately 37° C., and a relative humidity which is 100%, or less, according to the rates of production and loss of moisture, the amount of moisture originally present, and, to a less extent, depending on the composition of perspiration. As standard test conditions, the rate of transfer of moisture is measured from a water surface at 37·5° C. through the fabric into free still air at constant temperature and humidity (20·5° C., 63% R.H.), the distance between the fabric and the water surface being maintained constant.

The method of test consists in measuring, by weighing, the rate of escape of water vapour into the air-conditioned room from a shallow glass vessel covered with one layer of fabric, the water in the dish being maintained at the desired temperature by a surrounding water bath. To carry out a test, the sample is fastened by means of seccotine over the mouth (of area equal to 65·5 sq. cm.) of the vessel filled with water to within a distance of one-half inch from the fabric, no definite tension being employed beyond that necessary to prevent the fabric from sagging. The apparatus is arranged to test seven dishes in the same run. The dishes are placed on a wire tray in the water bath, which is thermostatically controlled to within 0·03° C., and the evaporation is determined by removing a vessel after a measured time interval, rapidly drying it and weighing. The vessel is replaced if

necessary for continued evaporation, and the period of removal from the bath occupies 2–3 minutes.

The rate of transfer is thought to be somewhat sensitive to stray air currents which exist unavoidably in a room in which movement takes place, and which are also induced by the action of the humidifying plant conditioning the air of the room. For this reason, and in addition, to submit each specimen to exactly the same conditions, the positions occupied by vessels in the bath are changed at regular intervals in a definite sequence. In order to determine the rapidity with which equilibrium is attained, weighings have been made at intervals throughout a day's run, but no evidence has been furnished that the rate determined for the first period differs appreciably from that at any subsequent period, and consequently the test has been made continuous, avoiding the disturbance of conditions which arises on removal of a dish from the bath for weighing. The time of run is limited to not more than four hours, since a longer period would involve an appreciable change in water level, with consequent variations. The rate of moisture transfer is expressed in grams per second per 1,000 square centimetres of surface, which involves the assumption that the rate is proportional to the area of fabric. This assumption is not strictly correct, but the method adopted for the expression of the results is justified, however, on the grounds of convenience, and, since all measurements recorded in this paper have been made on pieces of fabric of the same area and shape, no error is thereby introduced into the figures in this paper, which are purely comparative. A test of the validity of the assumption gave the following results for a given type of fabric.

Rate of Moisture Transfer	Area of Fabric
0·0056 gm./sec./1,000 sq. cm.	18·0 sq. cm.
0·0054 gm./sec./1,000 sq cm.	65·5 ,,

(2) Discussion of Results

A number of fabrics have been tested, and the results, together with information concerning their structure, are included in Tables I and II.

Table I

Fabric Letter	Description of Fabric (All Fabrics Bleached White)	Mean Rate of Transference in gms./sec./ 1,000 sq. cms.	No. of Tests	Permeability to Air "*P*"	Weight lb. per sq yd.
U	Plain weave. No filling	0·0055	4	2·2	0·08
R	,, ,, ,, ...	0·0054	4	3·0	0·19
S	,, ,, ,, ...	0·0053	11	—	0·15
A1	,, ,, Back filled. Calendered	0·0052	3	0·03	0·31
H	,, ,, ,, ,, ,,	0·0052	3	0·02	0·29
E	Drill. Starched. Calendered... ...	0·0051	4	0·49	0·30
B1	Plain weave. No filling. Singed ...	0·0051	3	3·5	0·16
C1	,, ,, Back filled. Calendered	0·0050	2	0·07	0·33
Q	,, ,, Filled. Heavy calender	0·0050	3	0·37	0·19
C	Weft sateen	0·0049	5	0·15	0·37
A	Duck	0·0049	6	0·28	0·52
D1	Cellular woven fabric	0·0049	4	—	0·22
B	Acid treated drill. A semi-parchmentised fabric, produced according to a patented process, using strong sulphuric acid	0·0049	1	0·05	0·44

Mean rate for open water surface, 0·0144 gm./sec./1,000 sq. cms.

Table II

Fabric Letter	Description of Fabric (All fabrics bleached white)	Mean Rate of Transference in grms./sec./1,000 sq. cms.	No. of Tests	Weight lb. per sq. yd.
V	Celanese self-stripe knitted. Acetate silk ...	0·0050	2	0·23
Z	Gauze fabric "Ninon." Acetate silk	0·0054	2	0·06
X	Plain weave. Acetate weft. Viscose warp ...	0·0050	2	0·17
W	Sateen. Viscose weft. Cotton warp	0·0050	2	0·20
Y	Knitted fabric. Hollow viscose yarn.	0·0053	1	0·17

The fabric letters refer to the series of fabrics tested in connection with the determination of absorption, transmission and reflection of radiant heat described in the preceding paper.

The degree of accuracy attainable is indicated by the fact that a deviation of 0·0002 gm./sec./1,000 sq. cms. from the mean rate for any given fabric is exceeded on one occasion only (when 0·0003 gm./sec./1,000 sq. cms. resulted), the mean of all the deviations being slightly less than 0·0001 gm./sec./1,000 sq. cms. Table I includes results of tests on a variety of cotton fabrics which differ widely in construction, and particularly in openness of weave, among the fabrics being some supplied as typical of those exported to the tropics, notably the heavily filled fabrics and the cotton duck. In Table II the results are recorded of a smaller number of tests on some artificial silk and artificial silk and cotton union fabrics. It will be observed that their range of moisture transfer falls within that obtained for cotton fabrics.

A column of figures is included in Table I which gives the value of the permeability to air, "*P*," for most of the fabrics. The details of the measurement are described later, the results being quoted here to emphasise the wide variation from fabric to fabric. Permeability to air is expressed as the volume of air (in litres) passing per unit time (1 sec.) through unit area (1,000 sq. cms.) under unit pressure difference (1 mm. of water) between the two sides of the fabric.

Variations in rates of transfer on different samples of any particular fabric are not thought to be due to a sampling effect, but are inherent in a measurement of this type. Considering the widely different nature of the fabrics tested, the range of rates of transfer is surprisingly small. It is in view of this result that sampling errors are not considered likely to occur, and that the tension under which fabrics are fastened on the dishes is not important. The general tendency of these results is confirmed by previous work from two different sources. A United States Bureau of Standards publication[1] on the transfer of moisture by blankets, employing a method on which the standard method of test adopted in this account was based, states that the range in the rates of moisture transfer of a large assortment of blankets was from 0·0032 to 0·0044 gm./sec./1,000 sq. cm. In a report of the Medical Research Council[2] a few tests are reported on the transfer of moisture to and from a liquid surface at room temperature through fabrics. The conclusion was drawn from tests on five fabrics, including three cotton shirtings, a cellular woven material and flannel, that all these materials allow water vapour to penetrate with almost equal ease. It appears to be established fairly conclusively that there is no large variation in moisture transmitting

power of fabrics under the conditions of experiment described above, such as might reasonably be expected to occur.

Part II

THE MECHANISM OF THE TRANSFER OF MOISTURE BY FABRICS UNDER STANDARD CONDITIONS OF TEST

The passage of moisture from the liquid surface to the outside atmosphere may be divided into three stages—(1) between the liquid surface and the under side of the fabric, (2) through the fabric, and (3) between the upper surface of the fabric and the free atmosphere which is in contact with it. It will be assumed that the steady state has been attained, in which moisture is passing at a definite rate, the vapour concentrations being constant at any one point. The investigation is divided into two sections, (1) the determination of vapour concentrations at various stages in the moisture transfer, of which only the concentrations at the two fabric surfaces are unknown, and (2) an examination of the mode of passage of moisture through the fabric and of the extent to which this can be accounted for by diffusion alone.

(1) Determination of Vapour Concentrations at Various Stages in Moisture Transfer

A number of subsidiary determinations are necessary to supply the data for this discussion.

(*a*) *A Pile Method for the Determination of the Concentration Gradient through a Fabric.*—The principle of the method is indicated by a cross-section of the apparatus shown in Fig. 1. The arrangement allows of the passage

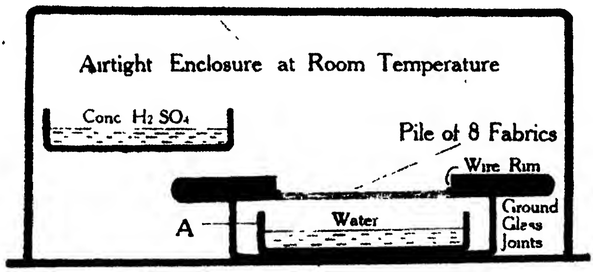

FIG. 1

of moisture from water contained in a dish A (which may be removed for weighing), through a pile consisting of eight layers of the material in contact with each other, into an atmosphere which is maintained at low humidity by means of dishes containing concentrated sulphuric acid placed in an air-tight enclosure. No temperature control has been attempted, the temperature being that of the room. Equilibrium is attained in a period of days, after which the rate of transfer is measured and also the regains of successive layers in the pile. Previous to the test the fabrics were saturated over water, so that reference to the desorption regain-relative humidity relationship (roughly the same for the five fabrics tested) enables the equivalent relative humidity gradient through the pile to be determined. This gradient within the limits of accuracy attainable is linear and proportional to the rate of moisture transfer. The gradients of five types of fabric are expressed in Table III for a constant rate of transfer of 0·0009 gm./sec./1,000 sq. cms., the direction of transfer being upwards.

Table III

Fabric Letter	Description of Fabric	Relative Humidity Gradient per Layer of Fabric
U	Plain weave. No filling	1·0
C	Weft sateen	1·3
R	Plain weave. No filling	1·5
A	Duck	3·2
B	Acid treated drill	6·3

The letters U, C, R, etc., have the meanings previously ascribed. These results show that there is a considerable variation between fabrics in the resistance opposed to the transfer of moisture, but how the magnitude of this effect is related to the total concentration difference between liquid and outside atmosphere will be shown by a second application of this pile method to the actual standard conditions of test.

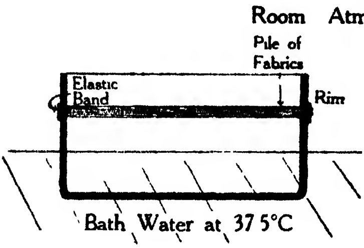

FIG. 2

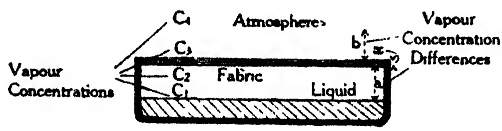

FIG. 3

(*b*) *A Pile Method Applied to Standard Conditions of Test*—A slight modification (shown in Fig. 2) of the standard method of test was found necessary, this involving the application of a rim in order to hold the pile of fabrics in position. In addition to the regain measurements on the attainment of equilibrium, it was necessary to determine the mean temperature of each layer of fabric, which was effected by placing copper-constantan thermojunctions between successive layers of fabric, the normal "cold" junction occupying the thermostatically controlled water bath. The results of temperature measurements are averaged, and, making due allowance for the temperature effect on the regain-relative humidity relationship for the fabric, the mean vapour concentration for each layer of fabric is calculated, being the product of the equivalent relative humidity and the maximum vapour concentration corresponding to the fabric temperature. Five layers of fabric R were tested by this method, the rate of transfer also being measured.

The vapour concentration in immediate contact with the liquid surface may be calculated from a knowledge of its temperature, with the aid of standard tables. The nominal temperature of the water is 37·5° C., but measurements employing a thermocouple between the liquid surface and the bath water indicate that the temperature is less than this, for which two reasons can be ascribed—(*a*) heat loss by radiation, and (*b*) heat loss by moisture evaporation from the water surface. Consequently the lowering of temperature is greater for an open water surface from which increased evaporation takes place. In the test, the temperature of the water surface in the fabric-covered vessel was 36·4° C., and in the open vessel 35·0° C.

The various concentrations of vapour obtained were—

	Concentration.
Atmosphere. 65·8% relative humidity. 21·2° C.	$12{\cdot}1\times10^{-6}$ gm./cc.
Water surface. 100% relative humidity. 36·4° C.	$42{\cdot}2\times10^{-6}$ gm./cc.
Concentration difference per layer of fabric R	$1{\cdot}85\times10^{-6}$ gm./cc.
Mean concentration of five layers of Fabric R (mean temperature 29·6° C.)	$23{\cdot}5\times10^{-6}$ gm./cc.

Rate of moisture transfer, 0.0035 gm./sec./1,000 sq. cm. (Height of rim 1·3 cm. Area of cross-section of dish, 56·7 sq. cm.) For one layer of Fabric R tested under the same conditions, the rate of transfer was 0·0045 gm./sec/. 1,000 sq. cm.

Referring to the diagrammatic representation of moisture transfer (Fig. 3), $a=C_1—C_2$; $b=C_3—C_4$; $x=C_2—C_3$. Let $a+b+x=F$, where F is the total concentration difference between the liquid surface and the outside atmosphere. It may be assumed that the transfer of moisture from the water surface is governed by a coefficient of moisture transmission (the "overall" coefficient) M such that rate$=M(C_1—C_4)=M.F.$ This is made up of three "partial" coefficients of moisture transmission—

K=coefficient of moisture transmission from liquid surface to fabric.
K_1=coefficient of moisture transmission from fabric to air.
K_2=coefficient of moisture transmission per layer of fabric.

We then have rate$=M.F.=K.a=K_1.b=K_2.\frac{x}{n}$ (equation of continuity)

so that $\frac{1}{M}=\frac{1}{K}+\frac{1}{K_1}+\frac{n}{K_2}$ (equation for resistances in series), where n is the number of layers of cloth R.

K depends on the distance between the fabric and liquid surface and the diffusion constant;

K_1 depends on the diffusion coefficient, on the degree of movement of the air, and on the height of the rim surrounding the fabric;

K_2 depends in some way on the fabric.

Substituting the figures given above, in the equation of continuity, $K=249$, $K_1=517$, $K_2=1891$, cm./1000 sec., so that, under the conditions of experiment the moisture transmission rate will be

$$\text{Rate}=\frac{C_1-C_1}{\frac{1}{249}+\frac{1}{517}+\frac{n}{1891}}\ \text{gm./sec./1000 sq. cm.} \qquad (1)$$

For the same rate, the concentration difference between the fabric and the outside air is approximately one-half that between the fabric and the liquid surface, that is, there is greater freedom of exchange outside the fabric than under it.

The equation (1) is not valid when $n=0$, since then the conditions will be such as to make K more nearly equal to K_1. The rate of transfer for one layer of fabric R should be

$$\text{Rate}=\frac{(42{\cdot}2-12{\cdot}1)\times10^{-6}}{\frac{1}{249}+\frac{1}{517}+\frac{1}{1891}}=0{\cdot}0046\ \text{gm./sec./1000 sq. cm.}$$

An actual test gives the value of rate=0·0045 gm./sec./1000 sq. cm., which is in good agreement.

When there is no rim to the vessel (i.e. under ordinary standard conditions of test), K_1 assumes an increased value, which, as a result of an experiment now to be described, is shown to be equal to $K \times 3{\cdot}6 = 896$.

(*c*) *Determination of Mean Concentration of a Single Layer of Fabric under Standard Conditions of Experiment*—A fabric is chosen whose desorption regain-relative humidity relationship is known. Two dishes are prepared in the normal manner, one containing water and the other paraffin oil, both being covered by the same type of fabric C, which was saturated previous to use. After equilibrium has been attained, the fabrics are removed quickly and placed in weighing bottles and their regain determined. The use of the fabric over paraffin oil constitutes an indirect method of measuring the mean temperature of the fabric. Since no water vapour passes to or from the fabric, the concentration of vapour at the fabric is that of the room atmosphere. Making allowance for the influence of temperature on the regain-relative humidity relationship, the relative humidity "H" of the atmosphere with which the fabric is in equilibrium becomes known from the fabric regain. Then, the maximum vapour pressure at the temperature of the fabric is the product, room vapour pressure $\times 100/H$.

The temperature corresponding to this maximum vapour pressure may be read off from standard tables. Similarly for the fabric over water, the relative humidity of the atmosphere with which it is in equilibrium is determined, and, assuming the mean temperature of the fabric is identical with that of the fabric over paraffin oil, the mean concentration of vapour at the fabric can be determined. The various concentrations of vapour were-

Atmosphere—66% relative humidity at 21·1° C. ... $12{\cdot}0 \times 10^{-6}$ gm./cc.
Water surface—100% relative humidity at 36·4° C. ... $42{\cdot}2 \times 10^{-6}$ gm./cc.

Mean concentration of fabric over water corresponds to 85·2% relative humidity at 24·8° C. ... ... $= 19{\cdot}2 \times 10^{-6}$ gm./cc.
Approximate estimation of concentration gradient through fabric for rate of transfer, 0·0050 gm./sec./1000 sq. cm. ... ... $= 2{\cdot}2 \times 10^{-6}$ gm./cc.
From which it follows that $K_1/K = 3{\cdot}6$.

The value $K_1 = 3{\cdot}6 \times K = 3{\cdot}6 \times 249 = 896$ is greater than the value $K_1 = 517$, found when a rim surrounded the fabric, which indicates that there is greater freedom of exchange with the outside atmosphere in the absence of the rim.

We should expect, for one layer of cloth R, under standard conditions of experiment,

$$\frac{1}{M} = \frac{1}{249} + \frac{1}{896} + \frac{1}{1891} \therefore M = 177$$

that is, rate $= 177(42{\cdot}2 - 11{\cdot}1)10^{-6} = 0{\cdot}0055$ gm./sec./1000 sq. cm., calculated as against 0·0054 gm./sec./1000 sq. cm. observed (Table I).

For an open vessel, K_2 does not enter into consideration, and the conditions are such that the diffusion is controlled by a coefficient approximately equal to K_1 (for a vessel with a rim). We then have

Rate $= 517(39{\cdot}2 - 11{\cdot}1)10^{-6} = 0{\cdot}0145$ gm./sec./1000 sq. cm.
calculated as against 0·0144 gm./sec./1000 sq. cm. observed (Table I).

(*d*) *Influence of Direction and Amount of Flow on the Coefficient of Moisture Transmission between Liquid Surface and Fabric*—The amount of moisture transmission can be reduced by replacing the water by an acid solution to

give 50% relative humidity, and the direction of flow reversed by employing concentrated acid in the dish. Some approximate measurements of temperature and regain of fabrics tested over (*a*) water, (*b*) acid solution to give 50% relative humidity, and (*c*) concentrated acid, gave the following values for K—

Water giving 100% R.H. $K=249, 227, 227, 208$.
Acid solution giving 50% R.H. $K=200$.
Concentrated acid giving 0% R.H. $K=222$.

There appears to be no change in the order of the value of K with reduction in rate, or on reversal of the direction of flow of moisture transmission.

(*e*) *Discussion*—The concentration difference for a single layer of fabric is seen to be small compared with the total concentration difference existing between the liquid and the outside atmosphere. A change in fabric concentration difference, which may occur, as reference to Table III shows, still does not bear a serious proportion to the total concentration difference, which explains why fabrics differing widely in construction have rates of moisture transfer within a comparatively small range.

Under conditions of still air outside the fabric, a reduction of the concentration difference required to pass moisture through fabrics would not result in an appreciable change, x being already small. It is possible to imagine a fabric constructed in the form of a very fine mesh which does not materially impede the passage of moisture. The effect of such a fabric would be merely to screen the air below it from free exchange with the air above. A large part of the action of a fabric in preventing the normal rate of flow taking place from a water surface is due to this screening effect.

If the degree of saturation at the skin is less than the maximum, or the temperature and relative-humidity of the atmosphere abnormally high, the rate of moisture transfer will be correspondingly reduced, but the range of variation between fabrics should not be affected.

The passage of a rapid stream of air over the outer surface of a fabric would tend to make K_1 large, in which case the rate would approach the value $F/(1/K+1/K_2)$, provided the air under the fabric remained undisturbed. Any such disturbance would increase the rate of moisture transfer. For one layer of fabric R, when $F=30\times10^{-6}$ gm./cc. concentration difference, the rate$=0{\cdot}0066$ gm./sec./1000 sq. cm.

Again, the condition of a garment in contact with a moist skin would make the concentration difference between liquid and fabric equal to zero, and K infinite (since K is inversely proportional to the distance between liquid and fabric). The rate of transfer for one layer of fabric would be $F/(1/K_1+1/K_2)$, which for fabric R ($F=30\times10^{-6}$ gm./cc.) equals $0{\cdot}0182$ gm./sec./1000 sq. cm., which is considerably in excess of the value $0{\cdot}0054$ gm./sec./1000 sq. cm. for the same fabric under standard conditions of test.

If a stream of air passes over a garment in contact with a moist skin, $1/K$ is zero and $1/K_1$ is decreased to an extent depending on the velocity of the air stream. The rate of loss of moisture will then depend very largely on the factor K_2. The relative humidity gradients per layer of fabric (corresponding to constant rate of moisture transfer) given in Table III, are proportional to the values of $1/K_2$ for each fabric, which constitute a measure of the fabric resistances.

One effect of the increase in rate of transfer under any set of conditions is that the proportion of the concentration difference through the fabric

to the total concentration difference is increased, thus extending the range of variation in rates of moisture transference.

The figures given in Table III show an interesting result, namely, that the resistance of the weft sateen C to moisture transfer is of the same order as that of fabrics R and U, and is considerably less than that of fabrics A and B, although in weight it is much more closely allied to the latter pair of fabrics. A probable explanation of this comparatively low resistance to moisture transfer will be advanced on p. T81. Under conditions where a fabric is in contact with a moist surface and if fanned by a breeze, fabric C would be definitely superior from the point of view of loss of moisture to fabrics A and B.

(2) An Examination of the Part Played by Diffusion in the Actual Passage of Moisture through the Fabric

An attempt to determine the part played by diffusion alone when moisture passes through a fabric was made by constructing a series of fabrics of a material which does not absorb moisture, so that transmission must take place by diffusion only. Both the size of the individual apertures and their number could be varied in a known manner within limits only restricted by difficulties of fabric construction.

Experimental Details—The material used for constructing the fabrics was ordinary writing paper impregnated with shellac varnish, which in addition to rendering the paper waterproof, provided a means of cementing the strips together. In the majority of cases the method of construction was to cut by means of a razor blade two sheets of paper together, in the manner shown by Fig. 4. After being varnished twice, the papers were

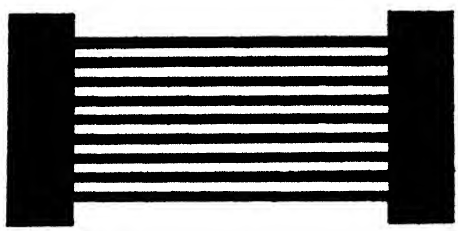

Fig 4.

laid together at right angles, a further coating of shellac binding them. In the following discussion the percentage aperture (%A) is the proportion of free air space expressed as a percentage of the whole area of the fabric. It was desirable to extend the fabric series to holes of smaller area than 0·01 sq. cm., and this was effected by piercing circular holes in copper foil. By enlarging the holes gradually with the tapered portion of a needle, and removing the raised edge with emery paper, a hole whose area could be determined with sufficient accuracy was readily obtained. The fabrics were tested under the standard conditions previously described, namely, loss of moisture from a water surface at 37·5° C., through the fabric into the conditioned atmosphere of the room.

Discussion—Results of tests on these fabrics are given in Table IV, indicating the relationship between the percentage aperture and rate of

transmission for four different areas of holes ranging from 0·004 to 0·16 sq. cm. The rates of moisture transfer are expressed in gm./sec./1000 sq. cm.

Table IV

Area 0·004 sq. cm.		Area 0·01 sq. cm.		Area 0·04 sq. cm.		Area 0·16 sq. cm.	
%*A*	Rate	%*A*	Rate	%*A*	Rate	%*A*	Rate
1·1	0·0011	0·9	0·0006	4·0	0·0019	4·0	0·0018
4·3	0·0030	4·0	0·0023	11·1	0·0041	11·1	0·0045
9·6	0·0041	11·1	0·0042	25·0	0·0060	25·0	0·0072
38·5	0·0056	25·0	0·0052	44·4	0·0069	64·0	0·0097
		44·4	0·0057	64·0	0·0086	79·0	0·0109

For each size of hole (0·004, 0·01, 0·04, and 0·16 sq. cm.) the rate of moisture transfer is plotted against percentage aperture in Fig. 5. It may be noted that the smaller the size of the individual apertures the steeper is

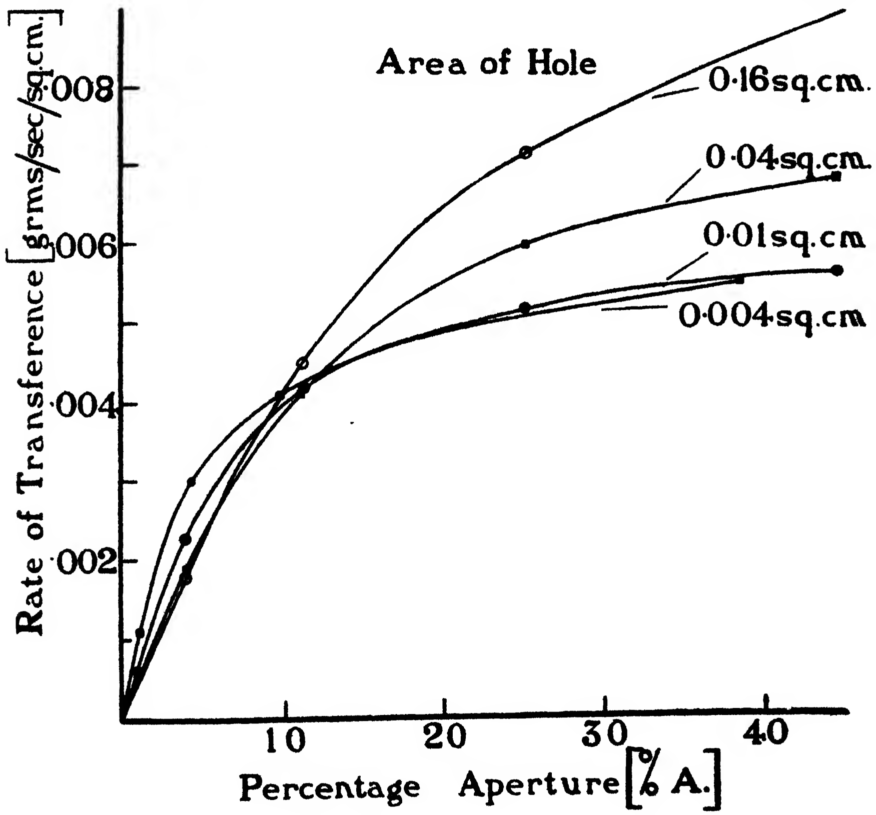

Fig. 5

the initial rise of the curve, which, however, is accompanied at a later stage by a greater flattening out. The results plotted in Fig. 5 admit of greater ease of interpretation if the rate of moisture transfer be plotted against area of hole for a series of constant percentage apertures of 4, 11, 25 and 44% respectively, the data being obtained directly from Fig. 5. These curves (Fig. 6) which are taken to the lowest practical limits of area of hole readily obtainable, appear to converge to a value for the rate of transfer equal to

0·0046 gm./sec./1000 sq. cms., which is not far below the weighted mean value of 0·0051 gm./sec./1000 sq. cms. for all the fabrics examined.

An explanation of the form taken by these curves is forthcoming as a result of some work by Brown and Escombe,[3] who investigated the purely physical processes by which the carbon dioxide of the atmosphere is able

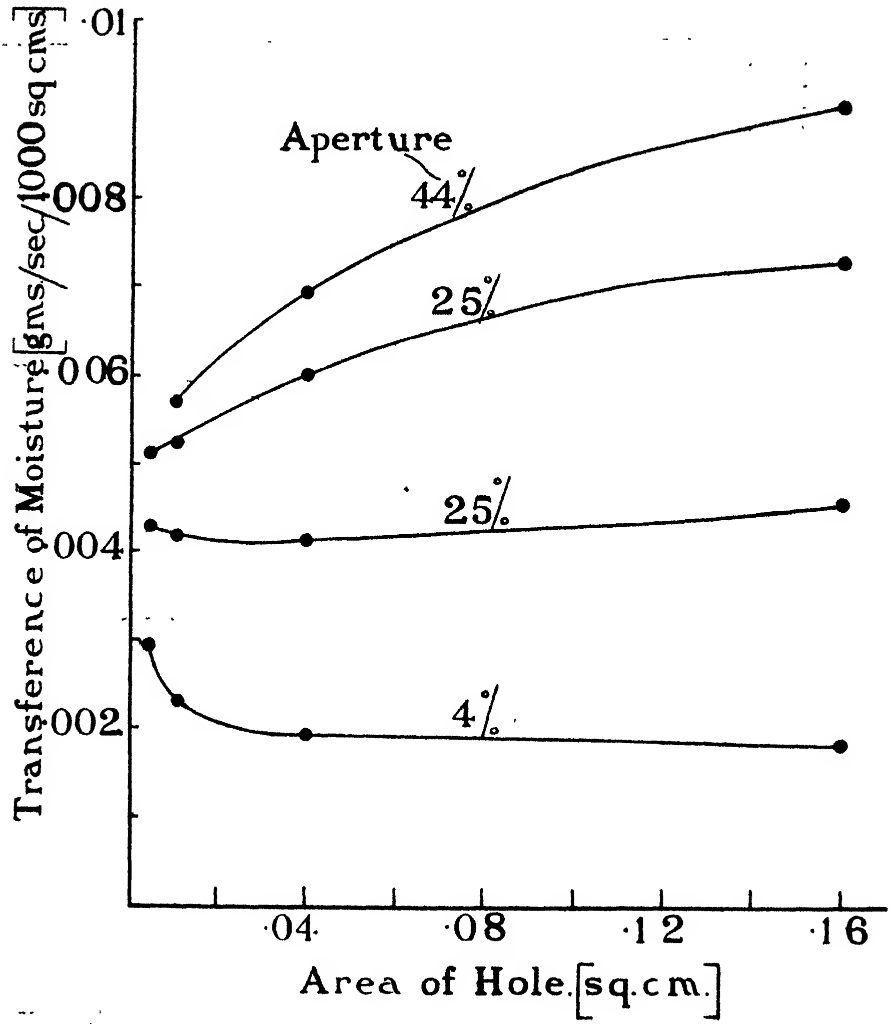

Fig. 6

to gain access to the active centres of assimilation in plants. This necessitated a study of diffusive phenomena generally, and especially of static diffusion, and led to important conclusions as to the remarkable influence exerted by perforated septa on the diffusive flow of gases and liquids generally. Their conclusions will be reviewed briefly.

"When a condition of static equilibrium has been established in a diffusing column of vapour, the amount of diffusion is proportional to the sectional area of the column If the mouth of the tube be partially obstructed with a septum having a circular aperture, or if such a septum be interposed anywhere in the line of flow, diffusion is modified in a remarkable and unexpected manner. The magnitude of the effect produced is found to be dependent on the linear dimensions of the aperture. It follows from this that

the rate of flow through unit area of such an aperture must vary inversely as the diameter."

"All the phenomena of diffusion through apertures in a diaphragm admit of a complete and satisfactory explanation if it be assumed that the converging or diverging lines of flow to or from the aperture result in the production of a system of "shells" of equal density, which locally alter the gradient in the immediate neighbourhood of the septum."

"The problem is analogous to that presented by the electric field in the neighbourhood of a conductor embedded in a surrounding non-conducting surface, and is capable of solution mathematically. For a diaphragm perforated with many small holes, a selection of the right number, size and distribution of the apertures ought to result in causing but little obstruction in the diffusive flow, although the combined areas of the apertures might only represent a comparatively small percentage of that of the obstructing septum. It is observed by experiment that provided the apertures in the septum are set at a minimum distance of ten diameters apart, the flow through the screen approximates closely to that deducible from theory. Any closer setting results in interference taking place which reduces the flow through any given aperture."

A mental picture of the converging and diverging lines of flow to and from the apertures and of the system of shells may be obtained from Fig. 7. The spacing of the holes is assumed to be such that interference takes place; consequently at a comparatively short distance from the diaphragm the density shells are almost parallel to the diaphragm.

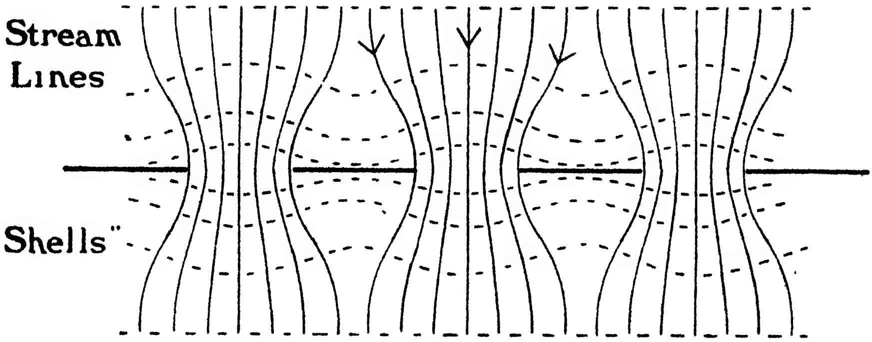

FIG. 7

If the rate of moisture transfer is calculated per unit area of aperture (equals rate $\times 100/A$ for unit area of 1000 sq. cm.), and plotted against spacing ratio (equals minimum distance between centres of holes divided by diameter of circular holes or side of square holes), the resulting curves (Fig. 8) show clearly the effect of mutual interference in reducing the rate per hole as the spacing of the holes is decreased. Again the rate of transfer per unit area of hole (when the interference between neighbouring holes is a minimum) is inversely proportional to the linear dimensions of the holes (of areas 0·004 and 0·01 sq. cm. respectively), although for holes of larger diameter, where the conditions for the production of density shells are not favourable, the rate is more nearly inversely proportional to the area of the holes. The transfer of water vapour by diffusion through a fabric or plate with small holes becomes sensibly independent of the number and size of the holes (i.e. of the percentage aperture). The reason for this state of affairs is that with many holes in a given area the flow through any given hole is reduced by the interference of its neighbours, but when there are fewer holes they are obviously farther apart, the mutual interference is less, and each hole passes more vapour than before. These conditions are seen to be fulfilled by most fabrics.

Some idea of the size of holes in a fabric may be obtained from Table V, which includes the results of some very approximate measurements on fabrics, made under the microscope.

Table V

Fabric	Percentage Aperture (% *A*)	Area of Hole, sq. cm.	Rate of Transfer, gm./sec./1000 sq. cm.
Net	95·5	0·030	0·0106
Z	64·0	0·002	0·0054
Cellular D.1	18·0 minimum	0·006	0·0049
U	23·5 ,,	0·00014	0·0055
S	9·4 ,,	0·00006	0·0053
Copper gauze ...	42·0	0·0025	0·0052
Sheet viscose ...	—	—	0·0050

It is seen that with the exception of the net fabric, which is not classed as an ordinary fabric, the maximum area of hole is 0·006 sq. cm., whilst for most fabrics, especially if closely woven, the area is considerably less.

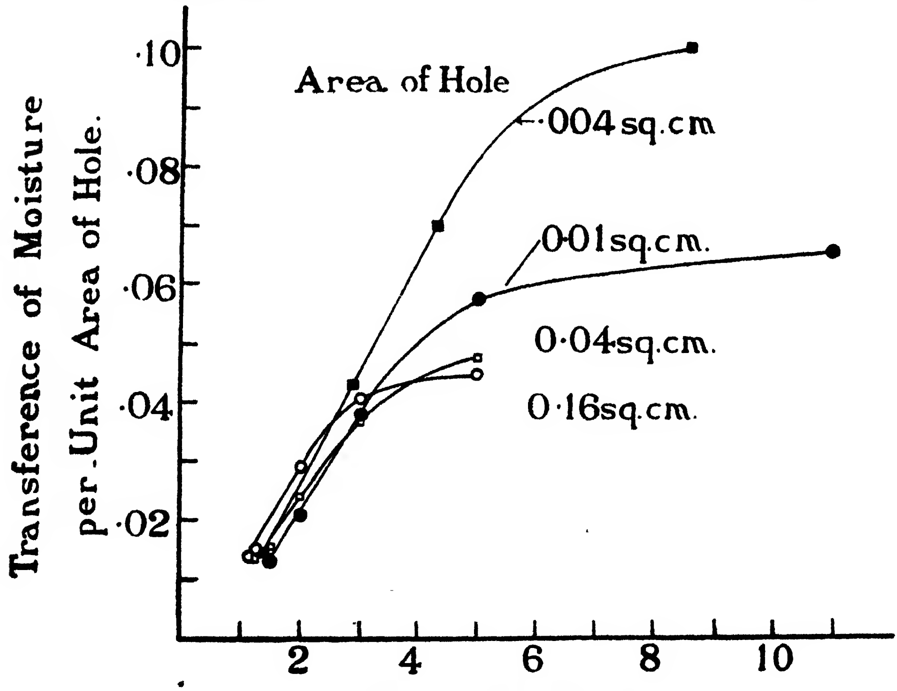

FIG. 8

It was noticed in some of the tests on the series of artificial fabrics that water was condensed under the fabric on the spaces between the holes. Had the material been capable of absorbing water the transmission would have been modified by the process of condensation, transmission through the material, and evaporation from the other side.

A sheet of viscose (which is non-permeable to air, so that diffusion of vapour in the sense previously considered cannot occur) has a rate of transmission of 0·0050 gm./sec./1000 sq. cm., which again is included in the normal fabric range. The sheet viscose when pierced by a large number of small

holes did not show more than the slight increase of 0·0002 gm./sec./1000 sq. cm. in rate of moisture transfer.

On varnishing the cellular fabric D1 with shellac, the smaller holes are sealed, and the cotton prevented from taking part in the moisture transference. There is little reduction in rate, the aperture remaining being approximately 18% and the mean area of hole 0·006 sq. cm. Applying these figures to the curves in Fig. 5, the rate of transfer which is shown to be 0·0044 gm./sec./1000 sq. cm. is in very fair agreement with the value of 0·0045 gm./sec./1000 sq. cm. obtained by actual test (value for normal fabric 0·0049 gm./sec./1000 sq. cm.).

A sample of fine copper gauze was tested, and measurements on this, together with the net and fabric W, fit in with the general trend of the curves of Fig. 6.

It may be concluded, then, that the passage of moisture through a fabric may be acounted for as taking place almost entirely by diffusion, and that the resistance opposed by the fabric is not dependent on the number and size of holes to any appreciable extent. If a fabric be sealed by filling, the transmission can still take place by the process of condensation, transmission and evaporation, with little decrease in rate. It follows as a result of this work that the rate of moisture transfer for a fabric cannot be increased above normal unless both the size of the holes and the percentage aperture are increased, which at once goes beyond the field of practical fabric construction. The nature of the particular fibre employed in the fabric construction would also appear to be immaterial.

A probable explanation may be given of the comparatively low resistance to moisture transfer of a sateen fabric, noted on p. T76. A sateen consists largely of floating threads, and consequently, instead of a series of small holes spaced as in a plain woven fabric, there are a large number of narrow slits close together. It has been seen that the resistance to the passage of moisture by diffusion is inversely proportional to the linear dimensions of holes, i.e. to the perimeters of the holes. The resistance therefore of the sateen fabric is comparatively low owing to this slit type of formation.

Part III

PERMEABILITY OF FABRICS TO AIR AND ITS RELATIONSHIP TO THE VENTILATING POWERS OF FABRICS

The conditions of wear allow of relative motion between the fabric and the body, which results in displacement of air either through the fabric interstices or through vents in the clothing. The air under the fabric is therefore in a state of turbulence to a certain degree, and is constantly de-saturated by admixture with air from outside the fabric. The freer the exchange of the air between the body and the clothes with that of the outside atmosphere, the more closely does the vapour tension of the air between the body and the clothes approach that of the outside atmosphere, with a consequent increase in the rate of loss of moisture.

This mode of transfer of moisture is described as ventilation, and is concerned with the passage of moist air as a whole, as distinct from passage by diffusion, which is, in comparison, a slower process. It has been remarked that the displacement of air can take place either through the fabric interstices or through vents in the clothing. It is obvious that for a fabric of very low permeability, ventilation can only take place through the vents, but such a fabric will exert a more efficient bellows action than a more open

one. On the whole it is probable that a fabric of high permeability is preferable to one of low permeability, since in the former instance the air between the fabric and the body has greater freedom of exchange with that of the outside atmosphere.

The ease of passage of air through a fabric is expressed by its factor of permeability, which is defined as the volume of air passing in unit time through unit area of fabric under unit pressure difference of the air on the two sides of the fabric.

Measurement of Permeability to Air

Fig. 9 shows the arrangement adopted for this determination. The fabric A is held against the open end of a cylindrical chamber B by means of a ring and spring clamps, to form a junction which is practically air-tight.

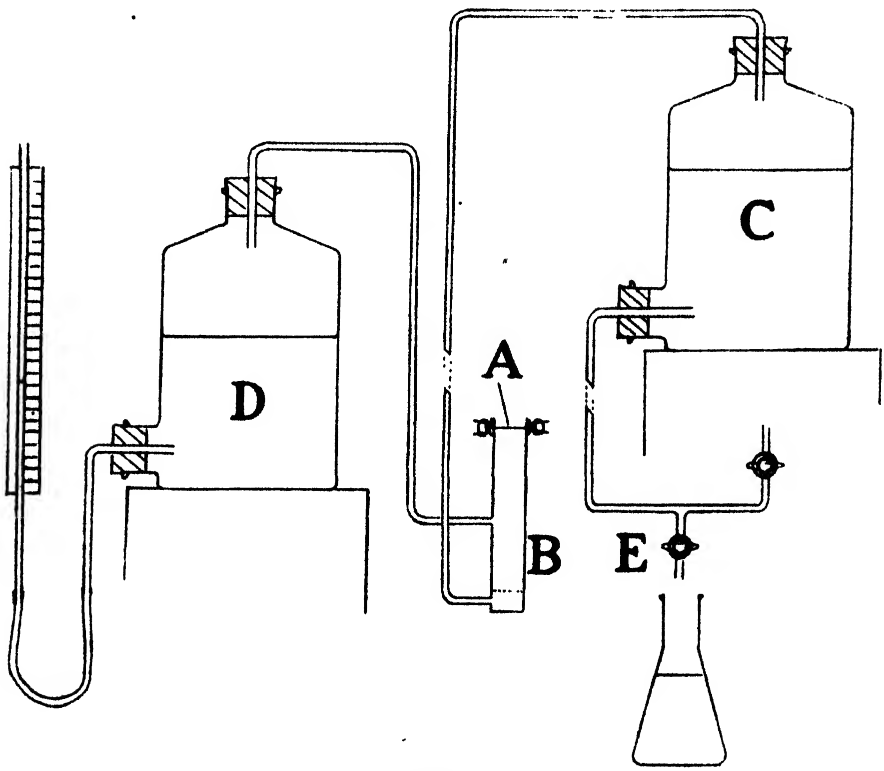

FIG. 9

An aspirator C is connected to an inlet near the base of the cylindrical chamber, a second inlet situated midway in the chamber being connected to a manometer D, which measures the pressure difference of the air on the two sides of the fabric.

When the aspirator is turned on, air of a determined humidity (controlled room atmosphere) is drawn through the specimen, resulting in a decrease in pressure of the air under the fabric. The rate of flow of the air drawn through the fabric is determined by measuring the volume of water run out through the tap E in a given time, a sufficient head of water (approximately 12 ft.) ensuring a constant rate of flow over the brief time occupied by one test. The correction to the volume of air measured in this way,

due to the pressure of the air being slightly less than atmospheric, is insignicant and therefore need not be applied. The rate of flow can be controlled by adjustment of the tap E, the aspirator being refilled when necessary from the water supply, tap E then being closed.

In order to obtain a measurable pressure difference, only a small area of fabric can be tested owing to the high value of the factor for permeability of cotton fabrics in general. Two cylinders are used, of areas of cross-section equal to 2·40 and 11·34 sq. cm. respectively, the cylinder of larger area being employed for fabrics of low permeability.

Eddies in the cylinder are avoided by having the fabric cover the entire cross-section of the cylinder, and by introducing a fine metal gauze in the cross-section immediately over the air outlet. The manometer consists of a large reservoir of water connected by means of a short length of rubber tube to a glass tube in contact with a scale. The pressure difference is read off on this scale, or if the movement of the water is small, a cathetometer is used and focussed on the meniscus in the manometer tube.

The apparatus measures the quantity of air forced through a definite area of fabric in a given time under a given pressure difference. The permeability is expressed as a volume of air in litres passing per second through an area of 1,000 sq. cm. under unit pressure difference of 1 mm. of water.

Discussion

A number of fabrics have been tested for permeability to air, *P.*, and the results are shown in Table VI.

Table VI

Fabric Letter	Description of Fabric	No. of Tests	"*P*"	% Mean Deviation	Area of Cross-Section of Cylinder sq. cm.
L	Ramie fibre. Plain weave Bleached	12	46·2	24·0	2·40
J	Ramie fibre. Plain weave. Unbleached	11	12·7	11·8	2·40
D	Cellular woven fabric	6	11·1	12·6	2·40
B1	Plain weave. No filling. Singed ...	12	3·53	11·3	2·40
R	Plain weave. No filling	11	3·03	6·9	2·40
U	Plain weave. No filling	12	2·21	14·0	2·40
G	Drill	12	0·57	7·4	2·40
E	Drill. Starched. Calendered	10	0·49	8·2	11·34
Q	Plain weave. Filled. Heavy calendar	12	0·37	8·6	11·34
A	Duck	11	0·28	7·1	11·34
C	Weft sateen	11	0·153	8·5	11·34
--	Filter paper	2	0·078	—	11·35
C1	Plain weave. Filled. Calendered ..	8	0·067	6·6	11·34
B	Acid-treated drill	16	0·054	30·7	11·34
A1	Plain weave. Filled. Calendered ...	11	0·026	8·5	11·34
H	Plain weave. Filled. Calendered ...	9	0·019	6·3	11·34

The factor "*P*" is seen to vary between the wide limits of 0·02–46, a ratio of roughly 2,300 to 1. Some idea of the variation from sample to sample in a given fabric can be gained from the column of figures giving the percentage mean deviation. The degree of variability is high, but does not appear to depend on *P* to any marked extent. There is no evidence that the factor *P* depends on the rate of flow (Table VII) within the range of rates of air flow employed.

It is a matter of great difficulty to assess the minimum value of permeability for efficient ventilation, as so many variables are involved. The

pressure difference generated by the movement of the fabric acts in such a direction as to restrain the motion, and depends in magnitude on the rate of movement of the fabric relative to the body and on the permeability factor.

Table VII

	Rate of Air Flow, ccs./sec./sq. cm.	"P" Litres/sec./1000 sq. cm./mm. Pressure Difference (Water)
Fabric B tested on large cylinder (area of cross-section, 11·34 sq. cm. ...	1·30	0·0201
	0·54	0·0215
	0·16	0·0204
Fabric G tested on small cylinder (area of cross-section, 2·40 sq. cm. ...	16·6	0·573
	4·2	0·605

Repetition of tests on given samples of fabric show the following results.

Fabric B (large variation between different samples)	Permeability "P"	
	Test 1	Test 2
Sample 1	0·069	0·070
Sample 2	0·028	0·027

A simple experiment was conducted which illustrates this point. A test dish was prepared, the rim being connected by a short length of camera bellows to a frame on which a fabric could be affixed, so that, on causing the frame to move up and down by mechanical means, air tends to pass through the fabric in alternate directions, there being no other outlet except through the fabric. Fabrics D (P=11·1) and E (P=0·49) allowed the frame to move at a rate of more than one complete oscillation per second, but fabric H (P=0·02) caused the lower dish to be disturbed, although it was of considerable weight. The fabric frame could only be moved relative to the dish at a very low rate under the application of considerable force.

It is apparent, then, that the forces which control the stability of the fabric (due to inertia, tension and stiffness), and which are fairly small, may be overcome by the pressure difference generated by even small rates of movement of fabrics of low permeability, so that the fabric tends to move relative to the body at a very slow rate; consequently, little exchange of moisture by ventilation takes place through the fabric. Beyond stating that a lower permeability factor is permissible for low rates of movement of fabrics in general, and for heavy or stiff fabrics as compared with light or limp fabrics, it is not possible to give any exact figure for the minimum permeability factor for efficient ventilation owing to the large variation in the forces controlling the stability of fabrics and owing to the dependence of this figure on the degree of motion of the fabric.

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TRANSACTIONS

6—THE CHEMICAL ANALYSIS OF COTTON

*THE REACTIVITY OF PLAIN AND MERCERISED, OR OTHER SWOLLEN, COTTONS

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(The British Cotton Industry Research Association)

I—INTRODUCTION AND SUMMARY

When cotton is treated with certain aqueous solutions, such as the caustic alkalis in suitable concentrations, it swells, or increases in volume, the swelling being associated with an increase in the absorptive capacity and an increased chemical reactivity of the washed material. This behaviour is utilised in a number of textile finishing processes, of which the most important is mercerisation. Urquhart and Williams[5] measured the changes in absorptive capacity which result from the swelling of different cotton materials in caustic soda solutions under various conditions, employing the absorption of water vapour from a humid atmosphere for this purpose. They showed that the ratio of the water absorption of the swollen cotton to that of the unswollen material at constant temperature is independent of the relative humidity of the atmosphere, that is, of the partial pressure of water vapour, and they called this ratio the "mercerisation ratio." It is probable that a similar constant ratio would be found for cotton which had been swollen in other solutions besides caustic soda, and the more generalised term "absorption ratio" is used in this paper. There exists at least a qualitative relation between the swelling, or the volume increase, of cotton in caustic soda solutions and the absorption ratio, though the difficulties of accurate measurement of volume are too great to render a quantitative comparison very significant.

The increased chemical reactivity of swollen cotton is displayed, for example, by an increased rate of hydrolysis of the cellulose with acids. This was first shown by Schwalbe,[4] who suggested the use of a figure called by him the "hydrolysis number," and defined as the increase in the copper number of cellulose materials which results from treatment with 5% sulphuric acid for fifteen minutes at the boil. The hydrolysis number is a measure of the chemical reactivity of the cotton. A simple expression of the chemical reactivity of cotton can also be obtained by measuring its copper number

* In this paper the word "plain" is used to describe cotton which has never been immersed in a liquid which causes swelling. This is an extension of the common technical usage of the word, which distinguishes between "plain" and "mercerised" cotton. Similarly the words "swollen cotton" are used to designate cotton which *has* been immersed in a swelling liquid. It is not implied that such cotton necessarily occupies a greater volume after the completion of the treatment than it did before, so that "swollen cotton" is to be regarded as a contraction of "cotton which has been swollen."

after oxidation with an alkaline hypobromite solution under conditions which are examined and standardised in this paper. The figure obtained by analysis is expressed as a ratio to that given by plain bleached cotton, and is called the "reactivity ratio" by analogy with the absorption ratio. The reactivity ratio of plain bleached cotton is therefore 1, whilst that of mercerised cotton or of cotton swollen in concentrated sulphuric acid solutions, is greater than 1 by an amount which depends upon the conditions of the swelling treatment.

The measurement of the copper number of cotton oxidised with hypobromite as a means of describing its reactivity possesses certain advantages over the method suggested by Schwalbe. Slight variations in the temperature or time of treatment of cotton with 5% sulphuric acid have a considerable effect upon the resulting copper number, and in the determination of Schwalbe's hydrolysis number it is therefore necessary to control carefully both factors. Owing to the peculiar nature of the oxidation of cotton with hypobromite, which is discussed later, the resulting copper number is, within certain limits, almost independent of the time and temperature of the treatment, and this is of considerable experimental advantage. All plain bleached cottons yield, within narrow limits, the same copper number when oxidised with hypobromite, irrespective of their geographical origin, mechanical form, and the nature of the bleaching process, and the reactivity ratio of cotton is even unaffected by *slight* overbleaching or acid attack.

It can be said of the reactivity ratio, with fewer reservations than would be necessary in the case of Schwalbe's hydrolysis number, that it describes uniquely the physical condition of cotton cellulose with respect to its "state of swelling," and is only affected by those reactions promoting the swelling of cotton.

In one experimental respect the method here suggested for describing the reactivity of cotton compares disadvantageously with that of Schwalbe, since the preparation of standard hypobromite requires more time and care than that of 5% sulphuric acid, and the reagent must be prepared afresh for every series of measurements. This disadvantage is compensated by the greater significance of the measurement.

It will be shown that a close correlation exists between the reactivity ratio and the absorption ratio of swollen cotton, and that the specific effects of temperature and concentration in the action of the caustic alkalis, and of concentrated sulphuric acid, upon cotton can be quantitatively followed by measurement of reactivity ratio. It affords a decisive means of distinguishing between a mercerised finish and other, mechanical, finishes in cotton fabrics.

Some comment is necessary on the system of nomenclature adopted. The term "reactivity ratio" may appear too general in view of the fact that the measurements with which this paper is concerned describe the reactivity of cotton cellulose in a specific chemical reaction, namely, its oxidation by hypobromite. No direct data are at present available to show whether the reactivity measured in this way can be accepted as a quantitative description of the behaviour of cotton cellulose, swollen and unswollen, in any other chemical reaction. Since, however, no confusion of terms is at present possible, a more precise and restricted nomenclature, such as "hypobromite reactivity ratio," has been avoided in the interest of brevity. A fuller justification of the general term "absorption ratio" also awaits the

proof that other forms of swollen cotton show the behaviour discovered by Urquhart and Williams in mercerised cotton, and even then a critic might demand the lengthened form "moisture absorption ratio," For these and other reasons future work may necessitate a review and modification of the nomenclature. This paper shows, however, that a close correlation exists between two independent measurements based respectively on an individual chemical reaction and an individual physical process, namely, the oxidation of cellulose by hypobromite and its absorption of water from a humid atmosphere. The existence of this correlation affords strong, if indirect, evidence that however individual (or specific) the experimental mechanism of measurement may be, the values obtained quantitatively describe general properties —"chemical reactivity" and "absorptive capacity"—of cotton cellulose.

II—DESCRIPTION AND DISCUSSION OF RESULTS

The experimental data which form the basis of the discussion in this section are presented in Section IV.

The Reactivity Ratio

It has already been reported (Clibbens and Ridge[2]) that when plain bleached cotton is brought into an alkaline hypobromite solution its copper number increases rapidly at first, but quickly attains a value which remains very nearly constant for some time. On the other hand, its absorption of basic dyestuffs, such as methylene blue, increases continuously with the time of contact of the cotton with the oxidising agent. Similar effects have now been observed when mercerised cotton is treated with hypobromite, but the constant copper number attained in the early stages of the oxidation is higher than that attained by unmercerised cotton under the same conditions. This behaviour is consistent with the following mechanism of oxidation. The first action of the hypobromite is to produce an oxidation product of cellulose of aldehydic character, possessing reducing properties and therefore a high copper number. In the next stage of the reaction this product is further oxidised, thus losing its reducing properties and copper number, and acquiring the acidic properties characterised by high methylene blue absorption. After the reactions have been in progress for some time a stage is reached at which the first, aldehydic, oxidation product is formed at the same rate as it is removed by further oxidation, and its total quantity then remains substantially unaltered for a time as the oxidation progresses further. The copper number of the oxidised material attains a maximum value which depends on the relative rates of the first and second processes. When the cotton has been swollen, as in mercerisation, the reactivity of the cellulose is increased and the rate at which the first, or reducing, product is formed is also increased. It is assumed that the rate of the second oxidation, which does not directly involve the unmodified cellulose, is unaffected by the swelling of the cotton. A maximum value of the copper number is again attained after the oxidation has been in progress for some time, but this is higher than the value attained with unswollen cotton on account of the relatively greater rate of the primary oxidation.

The copper number of cotton oxidised with hypobromite is, in the sense described above, a measure of reaction rate, or of the reactivity of the cotton, but it possesses the great experimental advantage over ordinary measurements of reaction rate that within limits it does not involve careful control of the time of treatment nor—as will be shown later—of the temperature.

Normal unswollen cottons varying widely in geographical origin and details of bleaching all yield values of the copper number near to 1·5 after a standard hypobromite treatment. The copper numbers resulting when mercerised or other swollen cottons are treated in the same way are greater than 1·5, and they are expressed as a ratio to this number—the reactivity ratio. The reactivity ratio of bleached, unswollen cotton is thus near to 1. The maximum reactivity ratio attained for normal cotton which has been swollen with caustic soda (mercerised) is 1·8, whilst cotton materials parchmentised with strong sulphuric acid may possess reactivity ratios of 2 or even more.

The Measurement of the Reactivity Ratio

The standard method of measurement is described in detail on page T92 *et seq.* In order to determine the degree of precision necessary in carrying out the measurement an investigation has been made of the effects of variations from the standard conditions. The concentration of the hypobromite itself ($N/10$) is the most important factor, whilst wider latitude is permissible in that of the excess alkali in the solution ($N/10$ sodium hydroxide). Neither the duration nor the temperature of action of the hypobromite solution needs accurate control.

As a basis for comparison, measurements are recorded for cottons of different origins scoured and bleached in different ways, and for trade mercerised samples. Among the large number of plain bleached cotton materials which have been examined, no reactivity ratios have been observed outside the limits 0·95 to 1·12. Trade mercerised materials generally yield values between 1·3 and 1·6, and the lowest value observed for any trade mercerised material was 1·2, which is still well outside the range of ratios obtained from plain bleached cottons; this sample, with an abnormally low ratio for mercerised cotton, was shown by other evidence to be very imperfectly swollen.

When the necessary hypobromite solution is available, the determination of reactivity ratio occupies only a little more time than the ordinary determination of copper number.

Applications of the Measurement of the Reactivity Ratio

(1) *The Effect of Treating Cotton with Caustic Alkali Solutions (Mercerising) under Different Conditions*—In Fig. 1 the reactivity ratio of cotton yarn treated with caustic soda solutions of different concentrations from 0 to $6N$ (0° to 45° Tw.), subsequently washed with water and air-dried, is plotted against the concentration of the alkali for two different temperatures of treatment, namely, 18° C. and −10° C. The curves show that the maximum effect of the alkali on the reactivity of the cotton is produced in lower concentrations at the lower temperature, a fact which has been recognised for many years in the technical process of mercerisation. Fig. 2 shows the curves obtained in a similar way from measurements made on the same cotton yarn treated with caustic potash solutions of different concentrations at the two temperatures, and the effect of lowering the temperature is again to produce the maximum increase of reactivity at a lower alkali concentration. Figs. 3 and 4 show the moisture absorption ratios of the materials used for the measurements of reactivity ratio given in Figs. 1 and 2. The forms of the reactivity and absorption curves are almost identical, and there is clearly a very close correlation between the two measurements. A third set of measurements has been made on the same yarns, namely, the shrinkage

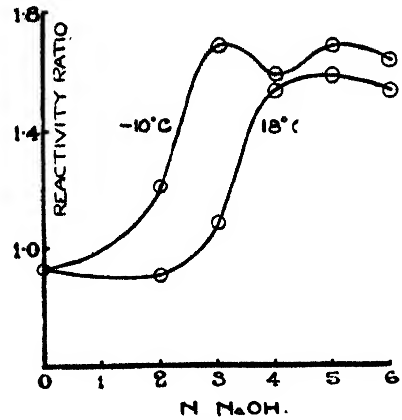


FIG. 1

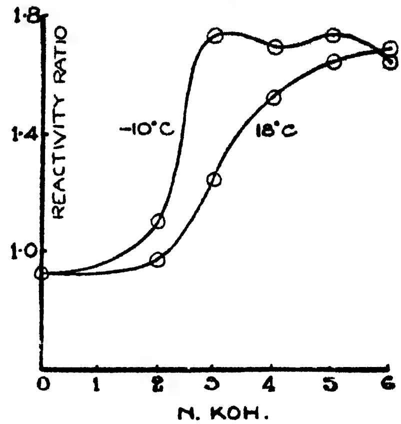


FIG. 2

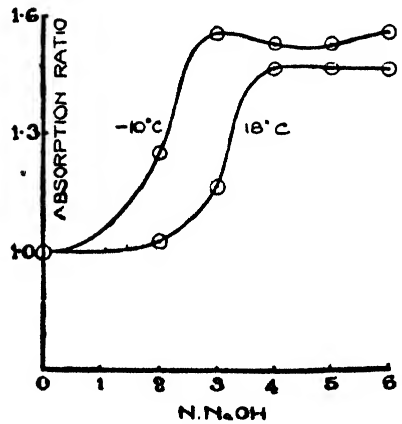


FIG. 3

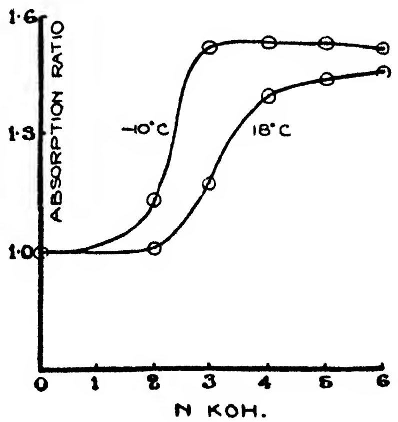


FIG. 4

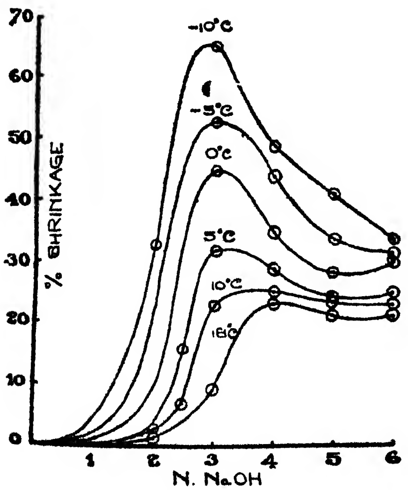


FIG. 5

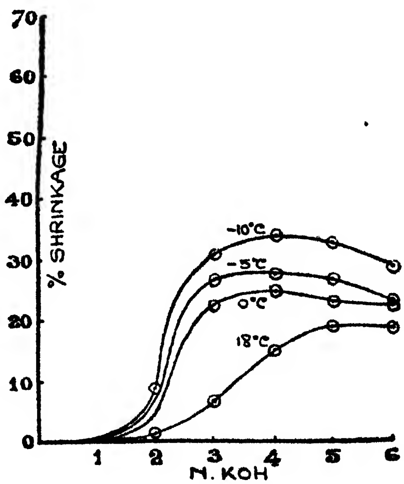


FIG. 6

in length which they experienced as a result of the alkali treatment. Fig. 5 refers to the experiments with caustic soda solutions, and a number of additional shrinkage curves are given for temperatures between 18° and −10° C. A very prominent maximum occurs in the shrinkage curve at low temperatures with $3N$ caustic soda, and the continuous development and growth of this maximum is the most striking feature of Fig. 5. The maximum shrinkage occurs with a lower concentration of alkali at −10° C. than at 18° C., but there is otherwise very little similarity between the shrinkage and the reactivity or absorption curves (Figs. 1 and 3); the great increase in shrinkage which occurs at low temperatures over anything attained at the ordinary temperature possesses no counterpart in the reactivity and absorption curves. Shrinkage curves for the yarn treated with caustic potash under the same range of conditions are recorded in Fig. 6. These do not exhibit the very prominent maximum characteristic of the caustic soda curves, and are more similar in form to the reactivity and absorption curves (Figs. 2 and 4). The effects of other minor factors upon the reactivity of mercerised cotton are summarised below.

(*a*) The reactivity ratio of cotton materials immersed in caustic soda of mercerising strength, and submitted to tension, is slightly less than that of the same material mercerised under the same conditions but without the application of tension. In this respect the reactivity and absorption ratios behave similarly (cf. Urquhart and Williams[5]).

(*b*) The reactivity ratio of cotton which has been mercerised after scouring (boiling with dilute caustic soda) is slightly greater than that of the same cotton mercerised under the same conditions in the grey state.

(*c*) The drying of mercerised cotton at a high temperature (110° C.) does not appear to affect its reactivity ratio. This is the only observed instance of a divergence between the behaviour of the reactivity and absorption ratios.

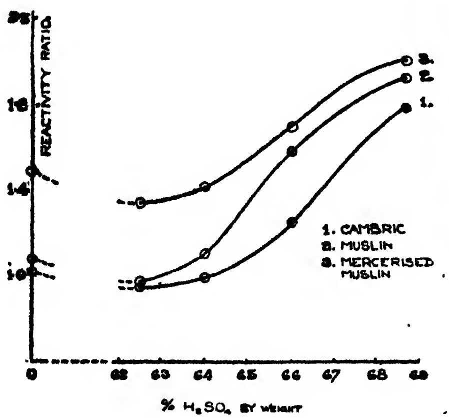


FIG. 7

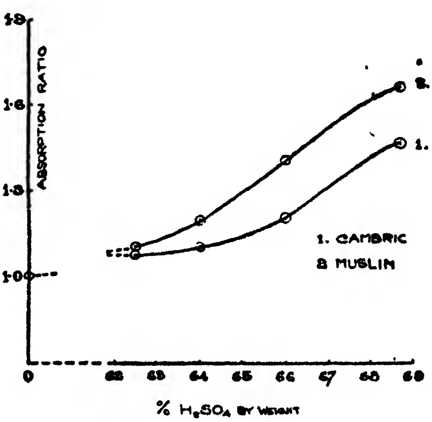


FIG. 8

(2) *The Effect of Treating Cotton with Sulphuric Acid Solutions (Parchmentising or Linenising) under Different Conditions*—When cotton is treated with sulphuric acid solutions above a certain concentration, it swells and acquires at the same time an increased reactivity. The following reactivity ratios have been observed, for example, in different trade materials finished with sulphuric acid—a parchmentised cloth yielded the value 1·6, which is

greater than the average attained in trade mercerisation; a transparent organdie possessed a reactivity ratio of 2·07, which falls entirely outside the mercerisation range, whilst for a linen finish obtained with sulphuric acid the value 1·23 was observed.

The swelling of cotton in sulphuric acid, unlike that in the caustic alkalis, does not reach a limit short of complete dissolution of the cellulose, and in describing the effect of sulphuric acid upon the reactivity of cotton, it is therefore necessary to define the duration of the acid treatment. The time must be short in order to avoid chemical attack of the cellulose, and the quantitative results obtained must be expected to vary from one cotton material to another under the same conditions of acid treatment, owing to the variations of spun and woven structure which control the extent of penetration of the acid during the short treatment.

Two plain bleached cotton fabrics, a cambric and a muslin, were treated for 15 seconds with sulphuric acid solutions ranging from 62% to 69% by weight at 20° C., and their reactivity ratios were subsequently measured. The results are illustrated in Fig. 7, curves 1 and 2, where the reactivity ratio is plotted against concentration of sulphuric acid. The two curves are similar in form, but the muslin (curve 2) acquired a higher reactivity ratio

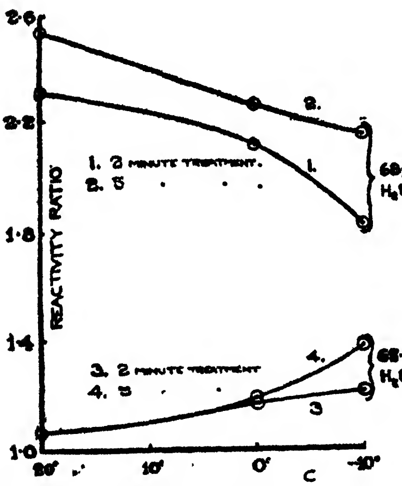


FIG. 9

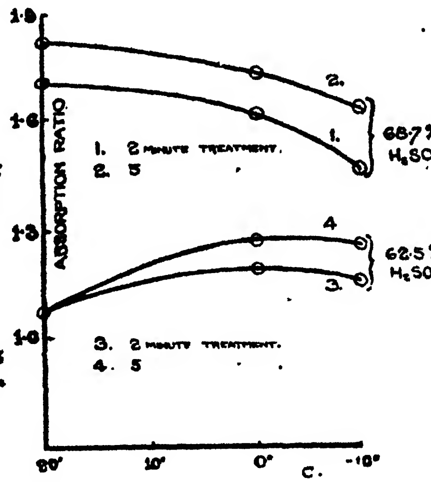


FIG. 10

than the cambric (curve 1) for the same acid treatment; this was to be expected, since the former possessed a more open structure than the latter. For all concentrations of acid up to 64% the effect upon the reactivity ratio of cotton is small—there even appears to be a slight fall in the ratio—but between 64% and 69% sulphuric acid there is an extremely rapid increase in reactivity with increasing acid concentration, and with the strongest acid employed values are attained much in excess of any which can be realised by mercerisation. The most striking feature of these curves is the extreme sensitiveness of the action to small changes of acid concentration within the range 64% to 69%. Fig. 8 gives the corresponding absorption ratio curves for the same materials, and the close resemblance between reactivity and absorption curves is again apparent. Fig. 7, curve 3, illustrates the results of reactivity measurements on the same muslin mercerised

prior to acid treatment. It starts from a higher point, corresponding to the greater reactivity of mercerised, as compared with plain bleached, materials; moisture absorption measurements are not available for the mercerised, acid finished muslin.

The influence of temperature on the reactivity changes produced in cotton by the swelling action of sulphuric acid is an unexpected one. In Fig. 9 reactivity ratio is plotted against temperature over the range 20° C. to −10° C. for two concentrations of sulphuric acid, namely, 68·7% and 62·5%. Two curves are given for each acid concentration, corresponding to durations of treatment of two and five minutes; in each experiment the longer duration produced the greater reactivity ratio, as was to be expected. With the more concentrated acid (68·7%) the reactivity ratio fell as the temperature fell, other conditions remaining the same, whilst with the less concentrated acid (62·5%) the reactivity ratio increased with falling temperature. In Fig. 10 the moisture absorption ratio is plotted against temperature for the same conditions of acid treatment as those represented in Fig. 9. The absorption curves differ slightly in form from the reactivity curves in the lower concentration of acid, but they show the same reversal of temperature effect on passing from the more to the less concentrated acid. The specific effects which accompany the swelling of cotton with sulphuric acid are accentuated by falling temperature in lower concentrations, and diminished by falling temperature in higher concentrations of acid.

III—EXPERIMENTAL METHODS

THE MEASUREMENT OF THE REACTIVITY RATIO

(1) Simplified Procedure

For many purposes sufficiently accurate results are obtained by the following procedure.

(*a*) *Preparation of the Hypobromite Solution*—The hypobromite solution is conveniently prepared from a stock standard solution of potassium bromate containing an excess of potassium bromide. By acidification of this solution free bromine is liberated in quantity equivalent to the bromate, and the correct volume of standard caustic soda solution is then added to neutralise the excess acid, to react with the free bromine yielding an equivalent quantity of hypobromite, and to furnish the necessary concentration of excess alkali when the mixture is diluted to a convenient total bulk.

The stock bromate-bromide solution contains 14·4 grams (weighed accurately to 0·1 gram) of pure potassium bromate and 60 grams (weighed to the nearest gram) of potassium bromide per litre. In order to prepare one litre of hypobromite solution, 200 cc. of the bromate solution are pipetted into a 1,000 cc. measuring flask and 200 cc. of 2*N* sulphuric acid added quickly from a measuring cylinder. The flask is stoppered immediately after the addition of the acid in order to prevent the escape of bromine, and the stopper is tied in position with string. The acid solution is allowed to stand for at least half an hour; it is sometimes convenient to carry out these operations on the day previous to that on which the measurements are to be made, and to allow the acidified solution to stand overnight, but in this case care must be taken to use a flask with a well-fitting stopper to avoid loss of bromine. The stoppered flask and its contents are cooled in running water, 250 cc. of 2*N* sodium hydroxide solution are added rapidly from a measuring cylinder, the stopper replaced, and the flask gently shaken, the

cooling being continued for a short time to avoid decomposition of hypobromite by the heat generated in the neutralisation of the acid. Finally the total bulk is made up to 1,000 cc., and the resulting solution should then be very near to $N/10$ in oxidising value and $N/10$ in free caustic soda. It should not be allowed to stand more than 24 hours before use, and its composition should be checked by titration as described later (page T94). The concentration of oxidising agent should lie between $0{\cdot}95 \times N/10$ and $1{\cdot}05 \times N/10$, and that of free alkali between $0{\cdot}9 \times N/10$ and $1{\cdot}1 \times N/10$.

The equations are—

(1) $KBrO_3 + 5KBr + 3H_2SO_4 \rightarrow 6Br + 3K_2SO_4 + 3H_2O$.

(2) $6Br + 6NaOH \rightarrow 3NaOBr + 3NaBr + 3H_2O$.

The stock bromate-bromide solution slightly exceeds $N/2$ in oxidising value. Since it is finally diluted five-fold (200 cc. to 1,000 cc.), the final solution is approximately $N/10$ in oxidising value. The amount of acid consumed in reaction 1 is exactly equivalent to the amount of alkali consumed in reaction 2. Since 200 cc. of $2N$ acid are used to liberate the bromine (a great excess), the subsequent addition of 200 cc. of $2N$ alkali would therefore produce an exactly "neutral" hypobromite solution in the stoichiometric sense. The actual addition of sodium hydroxide is 250 cc. of $2N$—an excess of 50 cc.—and this, diluted to 1,000 cc., corresponds to $N/10$ excess alkali.

(*b*) *Oxidation of the Cotton and Determination of the Copper Number*—One hundred cc. of the hypobromite solution are poured from a measuring cylinder into a 200 cc. stoppered bottle and 2·50 grams of the air-dry cotton under examination are introduced into the solution. The mixture is allowed to stand with occasional gentle shaking for 1½ hours if the temperature of the room is between 20° C. and 25° C., or for 2 hours if it is between 15° C. and 20° C. At the end of this time the cotton is filtered through a perforated plate, and washed in the funnel, (1) with water, (2) with a dilute solution of hydrogen peroxide to ensure complete removal of hypobromite, (3) again with water, (4) with dilute ($N/10$) sulphuric acid, and finally with water to a neutral reaction. The cotton is pressed as dry as possible on the funnel, and transferred to a conical flask, in which its copper number is determined by the usual Schwalbe-Braidy method[1] without further drying or weighing. The copper number, referred as usual to 100 grams of oven-dry material, is calculated on the basis of the 2·5 grams of air-dry material originally taken for the oxidation, a correction being made for its moisture content. The value so obtained divided by 1·5 is called the reactivity ratio.

(2) Accurate Procedure

The success of the method described above in yielding a solution which is exactly $N/10$ in oxidising value is affected by impurities in the bromate, by loss of free bromine from the acid solution, and by decomposition of hypobromite in the alkaline solution. Slight variations occur owing to these causes, and though they may be ignored for many purposes, as, for example, if it is merely required to know whether material has or has not been mercerised, the following more exact procedure for preparing hypobromite solutions of the correct concentration has been used to obtain most of the results recorded in this paper. In this method the hypobromite solution, slightly more concentrated than $N/10$, is prepared in a measuring flask of the form shown in Fig. 11. This has a bulb sealed into its neck, and is provided with two graduation marks, one at 1,000 cc. below the bulb and one at 1,100 cc. above the bulb. The 100 cc. of solution between the two marks is available for analytical determination of its precise oxidising value and alkalinity. Liquid can then be withdrawn from the flask until its

contents measure exactly 1,000 cc., and the necessary additions of water and standard alkali, calculated from the analyses, can be made to secure a solution exactly $N/10$ both in oxidising value and excess alkalinity. Two hundred and twenty cc. of the bromate-bromide solution prescribed above are run into this flask from a measuring cylinder, followed by 220 cc. of $2N$ sulphuric acid, also from a cylinder. The solutions are mixed by gentle shaking after the stopper has been replaced, and flask and contents are allowed to stand for at least half an hour. To the cooled acid solution 275 cc. of $2N$ sodium hydroxide solution are added from a cylinder, and the bulk finally made up to 1,100 cc., all the precautions mentioned under the simplified procedure being observed at each stage. The actual composition of the solution is next determined. For measurement of its oxidising value, 20 cc. are titrated against an accurate $N/10$ solution of sodium arsenite after the addition of 1 to 2 grams of sodium bicarbonate, starch-iodide paper being used as external indicator. For measurement of excess alkalinity, 20 cc. are treated with excess of dilute and carefully neutralised hydrogen peroxide solution in order to destroy the hypobromite, Methyl Red is added as indicator, and the solution titrated against $N/10$ acid. Two cc. of 10 volume hydrogen peroxide (roughly $2N$) are sufficient to destroy the hypobromite, and an unnecessarily large excess should be avoided or bleaching of the indicator will occur. The solution should prove to be slightly more concentrated than $1{\cdot}000 \times N/10$ in hypobromite —usually the factor lies between 1·02 and 1·03 —and it is adjusted so that the factor lies within the limits 0·995 and 1·005. In order to do this, solution is pipetted from the flask until the meniscus falls to the 1,000 cc. mark, and a previously calculated addition made to its volume. The alkalinity of the solution must be kept between $0{\cdot}9 \times N/10$ and $1{\cdot}1 \times N/10$, and if the calculated addition of water necessary for the adjustment of the hypobromite concentration fails to bring, or to maintain, the alkalinity within these limits, the addition must include a suitable volume of $2N$ sodium hydroxide or sulphuric acid. The solution is kept out of direct sunlight and stored in the dark as far as possible; it is used within 24 hours of the adjustment to the correct concentration.

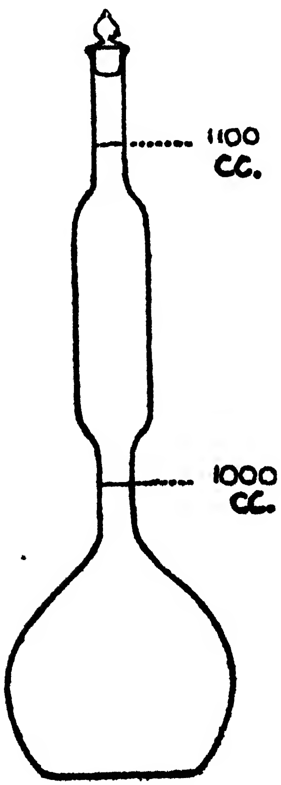


Fig. 11

The oxidation of the cotton and determination of its copper number are carried out as already described, except that the oxidation is continued for one hour only, and at a temperature of 25° C., the bottle and its contents being immersed in a thermostat at that temperature. In order to obtain the maximum accuracy, careful control of hypobromite concentration is the most important factor, as the results described in the following paragraphs show.

(3) The Effect of Variations in the Hypobromite Concentration

In different experiments the hypobromite concentration was varied between the limits $0{\cdot}9 \times N/10$ and $1{\cdot}1 \times N/10$. All other conditions remained the same as those described in the previous paragraph, the excess alkalinity being constant within the limits $0{\cdot}997 \times N/10$ and $1{\cdot}003 \times N/10$. The copper numbers resulting from the oxidation of a scoured cotton (No. 97R) with the different hypobromite solutions are given below.

Table I

Hypobromite Concentration	Copper Number	
$1{\cdot}099 \times N/10$	1·67 1·65, 1·69, 1·69	Mean 1·68
$1{\cdot}001 \times N/10$	1·60, 1·57, 1·57, 1·56	,, 1·58
$0{\cdot}901 \times N/10$	1·47, 1·47, 1·46, 1·46	,, 1·47

These figures show that a change of 0·1 in the hypobromite factor in the neighbourhood of $N/10$ produces a difference of 0·1 in the copper number, a difference which is greater than the experimental error of the copper number determination. Sufficient accuracy will be secured for most purposes, however, if the hypobromite concentration is kept within the range $0{\cdot}95 \times N/10$ to $1{\cdot}05 \times N/10$, although a still closer control has been maintained in the work described here.

(4) The Effect of Variations in the Alkali Concentration

In a further series of experiments the hypobromite concentration was kept constant within the limits 0·992 and $1{\cdot}001 \times N/10$, but that of the excess alkali was varied from 0·9 to $1{\cdot}1 \times N/10$. The effect of this variation upon the copper number of the scoured cotton (No. 97R) after one hour's oxidation at 25° C. is given below.

Table II

Concentration of Excess NaOH	Copper Number	
$1{\cdot}101 \times N/10$	1·57, 1·59, 1·61, 1·62	Mean 1·60
$0{\cdot}997 \times N/10$	1·57, 1·53, 1·57, 1·58	,, 1·56
$0{\cdot}902 \times N/10$	1·64, 1·61, 1·58, 1·58	,, 1·60

The table shows that a variation in the concentration of excess alkali between the limits 0·9 and $1{\cdot}1 \times N/10$ does not affect the measurement.

(5) The Effect of Variations in the Time and Temperature of the Oxidation

In Fig. 12 the copper number resulting from the oxidation of cotton with the standard hypobromite solution is plotted against the duration of the oxidation. Four curves are shown, three of which were obtained with plain scoured cotton (No. 97R) oxidised at 25°, 20°, and 15° C., whilst the fourth was obtained at 25° C. with the same cotton previously swollen in $5N$ caustic soda solution and washed (mercerised). All the curves are of the same form. They show that the copper number rises extremely rapidly at the beginning of the oxidation and reaches a maximum value which remains constant within the limits of accuracy of the measurement for a period of at least half an hour; further prolonged oxidation produces a slow fall of copper number. For the plain scoured cotton the maximum value attained is practically independent of the temperature, though the time taken to reach the maximum increases with falling temperature. The results illustrated in Fig. 12 are recorded below (Table III).

It is clear that within certain limits neither time nor temperature of the oxidation is an important factor. It is therefore suggested that no special

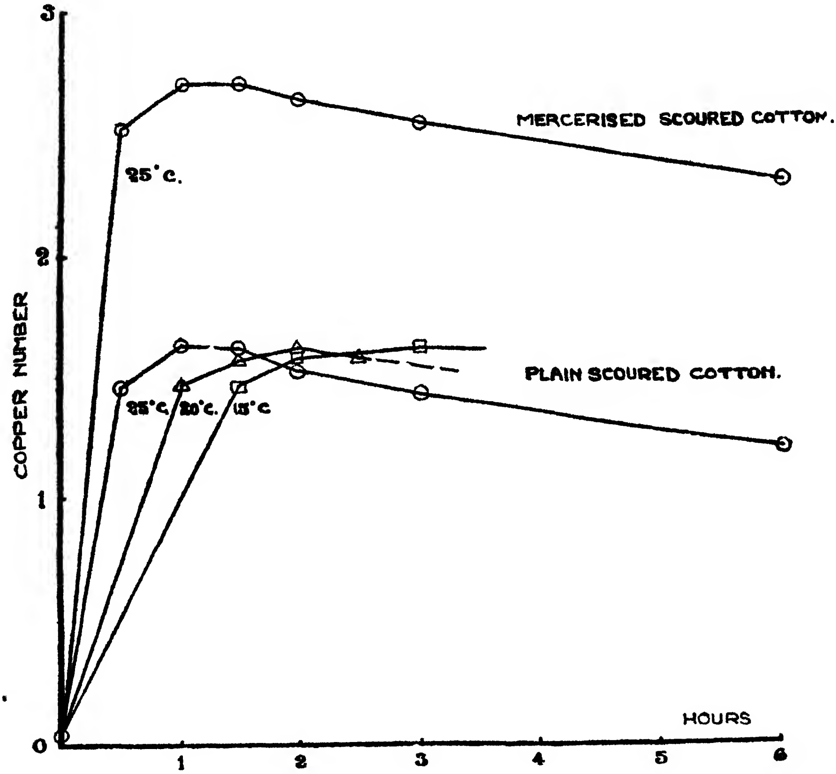


FIG. 12

Table III

Time of Treatment with Hypobromite	Copper Number			
	Plain Scoured Cotton No 97R			Mercerised Cotton 97R
	At 25° C.	At 20° C	At 15° C.	At 25° C.
0 Hours	0·05	0·05	0·05	0·05
½ ,, ...	1·46	—	—	2·54
1 ,, ...	1·64	1·49	—	2·71
1½ ,, ...	1·62	1·58	1·47	2·72
2 ,, ...	1·54	1·62	1·59	2·65
2½ ,, ...	—	1·58	—	—
3 ,, ...	1·44	—	1·64	2·56
6 ,, ...	1·21	—	—	2·34

precautions need be taken to control the temperature in the simple procedure for the determination of reactivity ratio, and that the oxidation should be allowed to proceed for 1½ hours at room temperatures between 20° and 25° C., and for 2 hours at room temperatures between 15° and 20° C. If

a thermostat at 25° C. is available, it is convenient to work at that temperature, thereby shortening the duration of oxidation to one hour. The relative unimportance of time and temperature is one of the advantages of this method for specifying the reactivity of cotton compared with any other method involving the measurement of rate of reaction.

The shape of the curves shown in Fig. 12, where copper number is plotted against the time of oxidation, can only be explained on the assumption that two consecutive reactions are in progress during the oxidation of cotton with hypobromite. It is suggested that the first reaction consists in the oxidation of cellulose to a reducing oxycellulose characterised by high copper number, and the second in the further oxidation of this substance to an acidic oxycellulose characterised by high methylene blue absorption. In the early stages of the hypobromite attack the amount of the reducing oxycellulose present is small, its rate of production from the cellulose is high, and its rate of removal by further oxidation low. The copper number of the material therefore rises rapidly. The accumulation of the reducing oxycellulose is accompanied, however, by an increase in the rate at which the acidic oxycellulose is formed from it, and a point is soon reached at which the reducing oxycellulose is removed by further oxidation at the same rate as it is produced from the cellulose. At this point the amount of reducing oxycellulose in the system, or the copper number of the material, is at a maximum. If the effective concentrations of the cellulose and the hypobromite remained substantially constant, the copper number, having reached its maximum, would suffer no further change on continued oxidation, but in practice it falls slowly from its maximum, as shown by the curves in Fig. 12. Two facts must be considered in relation to the shape of the copper number curve, and the value of the maximum copper number. First, the suggested reaction mechanism does not give a complete quantitative account of the oxidation, since other and more far-reaching processes are certainly in progress. The cotton suffers, for example, a fairly rapid loss of weight with progressive oxidation, due presumably to the formation of simple and soluble oxidation products such as carbon dioxide. In consequence of this, copper numbers would more logically be calculated on the weight of the oxidised material itself, and not on the weight of material taken for the oxidation as the analytical method specifies. It is, however, a great convenience to avoid, the drying and weighing of the material after oxidation, and, considered from the empirical analytical standpoint, it is justifiable to calculate copper numbers on the basis of the weight of unoxidised cotton. If the calculation is based on the weight of oxidised cotton the copper numbers are slightly higher, and the fall in the curve following the maximum is even slower than with the method here described (cf. Clibbens and Ridge[2]). Secondly, the concentration of hypobromite does not remain even approximately constant during the first few hours of the oxidation, but falls rapidly. The rate of this fall depends upon the ratio of the weight of cotton to the volume of hypobromite solution used, and both the exact shape of the curve and the actual copper numbers would therefore be expected to vary with this ratio. Table IV compares the copper numbers obtained by the standard method for the oxidation of 2·5 grams of cotton with 100 cc. of hypobromite for different times, with those obtained in otherwise identical manner by the oxidation of 2·5 grams of cotton with 250 cc. of hypobromite; the change in the concentration of hypobromite during the oxidation is also recorded.

Table IV

Time of Oxidation	Ratio of Cotton (No. 97R) to Hypobromite equals 2·5 gm./100 cc.		Ratio of Cotton (No. 97R) to Hypobromite equals 2·5 gm./250 cc.	
	Copper No.	Hypobromite Concn.	Copper No.	Hypobromite Concn.
0 Hours	0·05	$0{\cdot}998 \times N/10$	0·05	$0{\cdot}998 \times N/10$
1 ,,	1·65	0·703 ,,	1·70	0·884 ,,
1·5 ,,	1·62	0·642 ,,	1·72	0·831 ,,
3 ,,	1·47	0·406 ,,	1·54	0·718 ,,

The table shows that slightly higher copper numbers are attained with the larger volume of hypobromite.

The Measurement of the Reactivity Ratio when only Small Samples of Cotton are available for Analysis

For routine purposes the utility of the measurement, as described, is restricted by the facts that it cannot be applied in the presence of dyestuffs, and that the standard method requires the use of 2·5 grams of cotton—a larger sample than is often available. If the dye can be completely stripped by any of the usual methods, the test then becomes available for dyed goods, and it can be applied directly to the white background of finished fabrics containing woven coloured stripes. It is also possible to reduce the size of the sample to one-tenth of that specified in the standard method by taking advantage of the micro-method for the determination of copper number recently described by Heyes.[3] The hypobromite solution is prepared as already described, and 0·25 gram of the cotton material, contained in a stoppered vessel, is steeped in 10 cc. of the oxidising solution for one hour at 25° C. The cotton is then filtered, washed as already described, and its copper number determined by the Heyes method. Table V compares the values obtained by the standard method and the micro-method on six different materials, five of which are seen to be mercerised; the individual figures are the means of two or three determinations.

Table V

Sample No.	Reactivity Ratio Standard Method	Reactivity Ratio Micro-Method
C7	1·62	1·59
C9	1·51	1·51
C13	1·47	1·46
C17	1·56	1·57
S4062	1·27	1·25
97R	1·09	1·05

IV—EXPERIMENTAL RESULTS

The Effect of the Origin of the Cotton, and of the Conditions of Scouring and Bleaching, upon its Reactivity

Cottons of widely different geographical origin scoured under a wide variety of conditions all yield copper numbers near to 1·5 when submitted to the specified treatment. In other words, the reactivity ratio of scoured and bleached cottons is 1, and is not influenced by the variety of the cotton or by the conditions of scouring and bleaching. This conclusion is supported by a large number of measurements made on trade samples of bleached yarns and fabrics. Table VI gives the reactivity ratios of a number of yarns

spun from different varieties of cotton, and scoured together with the definite experimental object of determining the effect, if any, of the quality of the raw material upon its reactivity ratio.

Table VI

Cottons Scoured together for 6 Hours with 1% NaOH at 25 lb. Pressure

Variety and Reference Number of Cotton.	Reactivity Ratio.
147 American, Texas	1·01
74 American, Georgian	1·02
140 Egyptian, White Abassi	1·04
90 Sea Island	0·98
141 Indian, Native, Broach	0·96
145 Indian-American	0·96

Table VII gives the reactivity ratio of one cotton scoured in a number of different ways.

Table VII

Egyptian (Sakel) Cotton No. 148

Conditions of Scouring.	Reactivity Ratio.
3% NaOH for 6 hours at 40 lb. pressure	1·01
1% NaOH for 6 hours at 40 lb. pressure	1·01
1·3% Na_2CO_3 for 6 hours open boiling	1·07
1% NaOH for 6 hours at 50° C.	1·06

The bleaching of cotton materials with hypochlorite solutions is almost invariably accompanied by a rise, however small, in their copper numbers. The copper number of alkali boiled (scoured) cotton does not usually exceed 0·1, that of fully bleached printers' cloth generally lies between 0·1 and 0·2, whilst bleachers' and dyers' whites, and fully bleached yarns, may possess copper numbers from 0·2 to 0·3. Values exceeding this are comparatively rare, and cotton materials with copper numbers of 0·5 and above can fairly be described as overbleached. Thus a limiting range of copper numbers from 0 to 0·5 may be expected in normal trade whites, and it might be thought that such a possible variation in copper number would introduce considerable uncertainty in the measurement of the reactivity ratios of fully bleached goods, since this measurement depends upon the determination of copper number after a standard treatment. If a scoured cotton of original copper number 0·05 yielded a copper number of 1·5 after the hypobromite treatment it might be expected that the same cotton overbleached to an extent represented by a copper number of 0·5 would yield a value much above 1·5 after the same hypobromite treatment, and would thus appear to have acquired increased reactivity as a result of overbleaching. This is not so, however, and variations of copper number within the normal range of fully bleached cottons have no appreciable effect on measurement of reactivity ratio.

In Fig. 13 copper number is plotted against the time of action of the standard hypobromite solution at 25° C., (1) for a scoured cotton of copper number 0·05 (Curve 1), and (2) for cotton grossly overbleached with hypochlorite to extents represented by copper numbers of 0·8, 1·5, and 2·3 (Curves 2, 3, 4, respectively). When the scoured cotton of copper number near to zero is treated with the hypobromite solution, its copper number rises very rapidly in the first half hour of the action, then reaches a maximum of about 1·6. When the grossly overbleached cotton of copper number *greater than* 1·6 (Curve 4) is treated with the hypobromite solution under the same conditions, its copper number *falls* very rapidly in the first half hour of the action, and attains a value which is almost constant for a short

time, and which does not greatly exceed 1·6. The cotton with an original copper number of 0·8 (Curve 2), after an hour's treatment with hypobromite, yields a value which is only 0·1 in excess of that shown after the same treatment by the scoured cotton with an original copper number of only 0·05. It is clear from this that the normal variations of copper number in fully bleached goods can have no significant effect on the reactivity measurement. If the cotton, before treatment with hypobromite, possesses an enhanced copper number due, not to overbleaching (oxycellulose formation), but to acid attack (hydrocellulose formation), the action of hypobromite for one hour again brings the copper number to a value near 1·5, irrespective of its original value. Whilst the curves obtained for oxidised cottons (Fig. 13, Curves 2, 3, and 4) all lie slightly above that given by

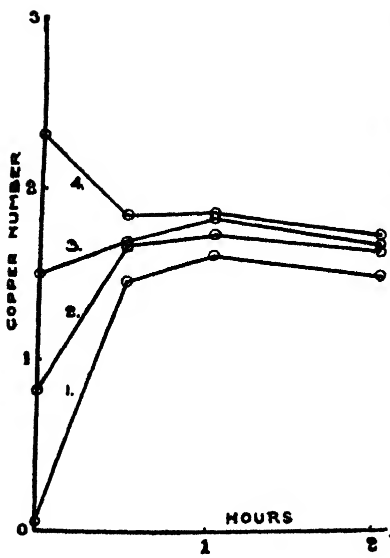


Fig. 13

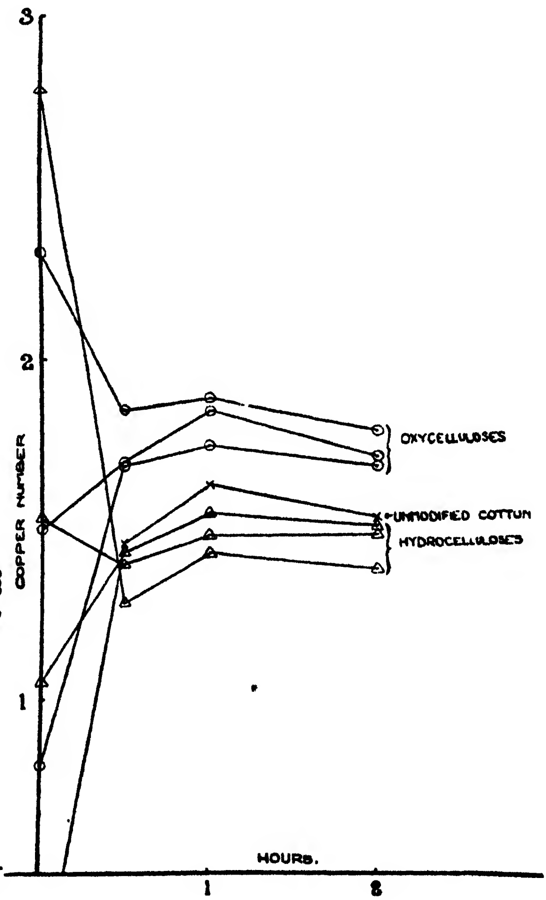


Fig. 14

normal scoured cotton (Curve 1), and are higher the greater the original copper number, the curves obtained for acid-attacked cotton all lie slightly below the normal curve, and are lower the greater the original copper number. In Fig. 14 copper number is plotted against time of action of the standard hypobromite solution at 25° C. for three scoured yarns, which, as a result of acid attack subsequent to scouring, possessed copper numbers of 1, 1·5, and 2·8. The curves already given (Fig. 13) for oxidised and normal

cotton under the same conditions are included in Fig. 14 for comparison with the acid attacked material. The figure shows that a wide range of original copper numbers—represented by the wide spread of points on the vertical axis and equal to nearly 3 copper number units—is reduced to a comparatively narrow copper number range of less than 0·5 after one hour's treatment with hypobromite. Hypobromite thus acts as an automatic copper number regulator for unswollen cotton.

The results illustrated in Figs. 13 and 14 are recorded in Table VIII.

Table VIII

Material		Copper Numbers after Hypobromite Treatment at 25° C for			
		0 Hours	½ Hour	1 Hour	2 Hours
Oxidised cotton	No OC7	0·81	1·69	1·75	1·68
,, ,, ...	No OC8	1·50	1·70	1·85	1·71
,, ,, ..	No OC9	2·31	1·85	1·89	1·78
Normal scoured cotton ...	No 97R	0·05	1·46	1·64	1·54
Acid attacked cotton	No C3	1·05	1·43	1·55	1·52
,, ,, ..	No C28	1·54	1·41	1·49	1·49
,, ,, ,,	No S15	2·78	1·29	1·43	1·39

OC7—Bleached cloth 182, oxidised 1 hour, N/25 NaOCl, pH7, 25° C
OC8—Bleached cloth 182, oxidised 2 hours, N/25 NaOCl, pH7, 25° C
OC9—Bleached cloth 182, oxidised 3 hours, N/25 NaOCl, pH7, 25° C
97R—Loose cotton, scoured with 1% NaOH at 40 lb. pressure
C3—Scoured yarn 70 C, treated with HCl, 100 grams lit., 48 hours, 20° C
C28—Scoured yarn 70 C, treated with HCl, 100 grams lit., 5·5 hours, 40° C
S15—Scoured yarn 70 C, treated with H_2SO_4 9·8 grams lit., 1 hour, 100° C

The Reactivity Ratio of Mercerised Materials

Table IX gives the reactivity ratios of white mercerised materials—fabrics and yarns of all kinds—collected at random and representing the normal production of a number of different works. The mean of all the

Table IX

Sample No	Reactivity Ratio	Sample No	Reactivity Ratio	Sample No	Reactivity Ratio
C1	1·58	C13	1·47	S4062	1·27
C2	1·52	C14	1·60	S4040	1·35
C3	1·39	C15	1·51	S4023	1·59
C4	1·34	C16	1·57	S4026	1·62
C5	1·46	C17	1·56	S4016	1·62
C6	1·41	C18	1·52	S4024	1·53
C7	1·62	C19	1·35	S3977	1·22
C8	1·51	C20	1·63	C182	1·34
C9	1·51	C21	1·63	CL92	1·31
C10	1·43	C22	1·53	CL150	1·34
C11	1·45	S4027	1·31	Y.A G.	1·42
C12	1·30	S4008	1·31	Y A	1·46

observations is 1·45, and the range 1·22 to 1·63; although this range is a fairly wide one, no sample of plain bleached (unmercerised and unswollen) cotton has ever been observed with a reactivity ratio within this range. Fig. 15 shows photomicrographs of sections through the warp of the mercerised

materials numbered C11, S4062, and S3977 in Table IX. These three samples were all white mercerised cloths of roughly the same construction, but whilst the reactivity ratio of the first is equal to the average, the last two possess the lowest reactivities recorded in the table. The photomicrographs show that the swelling of the individual hairs in the samples of low reactivity ratio was much inferior to that of the hairs in the average sample.

The Reactivity Ratio of Finished Materials

The measurement of reactivity ratio affords a decisive method for distinguishing between a mercerised and a purely mechanical finish. This is illustrated by the measurements recorded below, which were made on a number of trade cloths finished in different ways. The samples marked with an asterisk were stripped of their dye with hydrosulphite before the reactivity measurement was made.

Table X

Finishing Treatment.	Reactivity Ratio
Bleached only	1·04
Bleached, mercerised, beetled, hot calendered	1·65
Bleached, mercerised, dyed, glazed, and schreinered*	1·58
Bleached only	1·12
Bleached, dyed, glazed, and schreinered*	1·11
Bleached only	1·10
Bleached, dyed, cold calendered*	1·05
Bleached and beetled	1·12

The two finishing treatments that include a mercerising process are readily detected from an examination of the results

The Effect of Variations in the Conditions of Mercerisation upon the Reactivity Ratio and Other Properties

Three-lea skeins of a scoured 2/36's Egyptian yarn, accurately reeled to 54 inches girth, were immersed for five minutes in caustic soda and caustic potash solutions of different concentrations at different temperatures, they were then washed in hot water and dried in the air. The girths (or lengths) of all the treated skeins were measured under a load of 500 grams, and samples of the same materials were used for determinations of reactivity and absorption ratios. The latter was measured by exposing small samples in closed vessels to an atmosphere of constant humidity (70% saturated), obtained by the use of a sulphuric acid solution of suitable concentration. After the samples had attained constant weight their moisture contents were determined by oven-drying at 110° C., the absorption ratio being defined as the ratio of the moisture content of the swollen to that of the untreated cotton. The results have already been described and illustrated in Figs. 1 to 6, and they are recorded in Tables XI and XII. The most dilute solutions of both alkalis were super-cooled at −10° C.

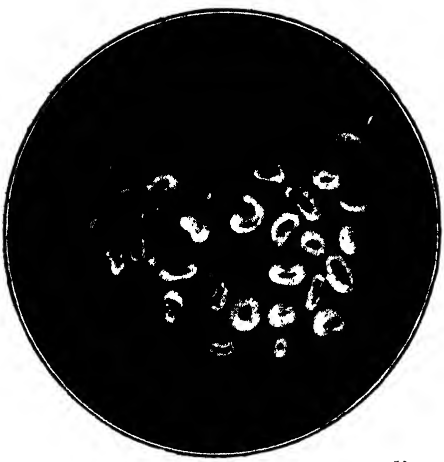
Table XI

Reactivity and Absorption Ratios

Concentration of												
NaOH	0	2	3	4	5	6N	—	—	—	—	—	—
or KOH	—	—	—	—	—	—	0	2	3	4	5	6N
Reactivity ratio of material treated at-												
18° C	0·95	0·92	1·09	1·55	1·60	1·54	0·95	0·98	1·25	1·53	1·65	1·69
10° C	0·95	1·21	1·69	1·60	1·70	1·64	0·95	1·11	1·75	1·71	1·75	1·65
Absorption ratio of material treated at-												
18° C	1·00	1·03	1·17	1·47	1·47	1·47	1·00	1·01	1·18	1·41	1·45	1·47
10° C	1·00	1·25	1·56	1·53	1·53	1·56	1·00	1·14	1·52	1·54	1·54	1·52

C 11—Reactivity ratio 1·45.

S 3077—Reactivity ratio 1·22



S 4062—Reactivity ratio 1·27.

FIG. 15

Cross sections of warp from mercerised fabrics

Table XII

Shrinkages

Concentration of NaOH or KOH	Per Cent. Shrinkage in Length									
	18° C.		10° C.	5° C.	0° C.		−5° C.		−10° C.	
	NaOH	KOH	NaOH	NaOH	NaOH	KOH	NaOH	KOH	NaOH	KOH
0 *N*	0	0	0	0	0	0	0	0	0	0
2 *N*	1·5	1·5	2·3	2·7	—	—	—	—	33·4	9·1
2·5 *N*	—	—	7·7	16·1	—	—	—	—	—	—
3 *N*	9·5	7·5	22·6	32·0	44·9	22·4	52·5	26·2	65·8	30·4
4 *N*	22·8	15·9	25·3	28·9	34·6	24·7	44·1	27·4	48·7	34·2
5 *N*	21·3	19·3	23·7	24·0	28·1	23·6	33·8	26·2	41·0	33·8
6 *N*	21·3	19·6	23·4	25·6	30·0	22·8	31·6	23·6	33·4	29·6

In order to determine the effect on the reactivity ratio of tension applied during mercerisation, skeins of 2/40's grey Egyptian yarn reeled to 54 inches girth were immersed in 5*N* caustic soda solution. After complete shrinkage had occurred, different skeins were stretched back to different girths, and washed off under tension. All the skeins were then scoured, and reactivity ratios determined with the following results.

54-in. Skeins (Reactivity Ratio 1·02), Shrunk in 5*N* NaOH

	And not Stretched	And Stretched Back to			
		52 inches	53 inches	54 inches	55 inches
Reactivity Ratio	1·59	1·51	1·47	1·46	1·47

The application of tension during mercerisation effects a small but definite decrease in reactivity. In the above experiments the yarn was mercerised grey and then scoured, but when the same yarn was first scoured and subsequently mercerised without stretching its reactivity ratio was 1·68, instead of 1·59 obtained from identical processing in the reverse order. These figures illustrate a fact which has been frequently observed, namely, that a lower reactivity results from mercerising cotton in the grey state than from mercerising scoured cotton under otherwise identical conditions. In order to make the comparison it is necessary that the grey mercerised sample should be scoured before determination of its reactivity ratio, since the measurement is of less certain significance when applied to grey cotton containing non-cellulose impurities in considerable quantity. The reactivity of mercerised cotton is not, however, appreciably affected by boiling it with dilute caustic soda. Table XIII shows that neither dry nor wet conditions of heating greatly influence the reactivity ratio of mercerised cotton.

Table XIII

Scoured Cotton No. 97R Treated as below.	Reactivity Ratio
(1) Immersed in 7*N* caustic soda, washed and dried in the air for two days	1·71
(2) As 1, but dried for four hours at 110° C., and conditioned in the air for two days	1·68
(3) As 1, but boiled with water for four hours before air-drying ...	1·70
(4) As 1, but boiled with 1% caustic soda for four hours and washed before air-drying	1·68

The Effect of Treating Cotton with Sulphuric Acid Solutions of Swelling Concentration upon its Reactivity Ratio

Samples of bleached cloth, and of bleached, mercerised cloth, were immersed in sulphuric acid solutions of different concentrations and at different temperatures for fixed times (½, 2, or 5 minutes). They were then washed in water and immediately boiled in soda ash to effect complete removal of acid. Air-dried samples were used for measurement of reactivity and absorption ratios by methods already described. The results recorded in Tables XIV and XV have been illustrated and discussed in an earlier section. Table XIV contains data on the effect of acid concentration upon reactivity and absorption ratios (Figs. 7 and 8) at constant temperature and for constant time of treatment, whilst the data in Table XV describe the effect of temperature with constant concentration of acid (Figs. 9 and 10).

Table XIV

Sulphuric Acid, ½ Min. at 20° C.

H_2SO_4% by Weight	Plain Bleached Cloth No. 248 (Muslin)		Mercerised Bleached Cloth No. 248 (Muslin)	Plain Bleached Cloth No. 249 (Cambric)	
	Reactivity Ratio	Absorption Ratio	Reactivity Ratio	Reactivity Ratio	Absorption Ratio
0	1·03	1·00	1·48	1·08	1·00
62·5	0·97	1·10	1·35	0·95	1·07
64·0	1·11	1·20	1·41	0·99	1·10
66·0	1·57	1·41	1·70	1·25	1·21
68·7	1·92	1·66	2·01	1·79	1·46

Table XV

Plain Bleached Cloth No. 249

Temperature	Two Minutes' Treatment		Five Minutes' Treatment	
	Reactivity Ratio	Absorption Ratio	Reactivity Ratio	Absorption Ratio
	62·5% Sulphuric Acid			
20° C.	1·07	1·06	1·07	1·07
0° C.	1·17	1·20	1·19	1·27
−10° C.	1·21	1·15	1·39	1·25
	68·7% Sulphuric Acid			
20° C.	2·31	1·70	2·54	1·83
0° C.	2·12	1·61	2·27	1·73
−10° C.	1·83	1·47	2·16	1·63

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7—STATISTICAL METHODS IN TEXTILE RESEARCH. THE ANALYSIS OF COMPLEX VARIATIONS

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INTRODUCTION

The use of statistical methods in textile research is rendered necessary by the fact that the materials are not uniform, so that the means of large random samples have to be compared. As a result of the variability, the means (and other constants) of these samples are subject to so-called random errors. The magnitude of these errors is often indicated by a "probable error," which is really a function of the variability of the mean, and is expressible in terms of the variability of the individual readings.* The simpler theory of these quantities has been in common use in textile research for years, and is described in several places. (See particularly reference 1.) In actual practice, however, the variations in many quantities are not homogeneous and random, but are a complex result of a few important causes, added to the infinity of small causes that may be regarded as producing the random variations; this complexity renders an uncritical "rule-of-thumb" calculation and interpretation of probable errors unreliable. The total variability must be analysed into its constituent parts, and when this has been done, the appropriate part can be used to find the correct probable error applicable to the problem. The analysis is also useful as estimating the relative importance of the few important causes. This general statistical problem has confronted workers in other fields (particularly in agricultural research), and satisfactory methods have been evolved by Fisher; they are described in his book "*Statistical Methods for Research Workers*."[3] So far, however, these more exact methods do not seem to have been much used in textile testing; but their application is direct, and it is the aim of this paper to explain and illustrate them by means of examples. The data used in the examples are all genuine but are selected as illustrating some statistical point, and no generally applicable conclusions can be drawn regarding their subject matter.

I—THE MEASUREMENT AND ANALYSIS OF VARIABILITY

There are several ways of expressing variability, but in this paper the quantity *variance* is used. The *mean variance* is equal to the square of the standard deviation, and is the mean squared deviation from the grand mean. It possesses the important property of being additive, i.e. if a quantity is subject to the operation of several *independent* causes, each of which contributes a certain variance, then the final variance of the quantity is the sum of the variances due to the several causes.

Let it be assumed, for example, that a quantity x is subject to random variations, and to other variations produced by two causes A and B. Then the value of any one observation of x is

$$x=\bar{\xi}+\alpha+\beta+\xi'$$

* Modern statisticians prefer to use the standard error instead of the probable error. If σ is the standard deviation of the individual readings, the standard error of the mean of a sample of $n=\sigma/\sqrt{n}$ and the probable error $=0{\cdot}6745\ \sigma/\sqrt{n}$. The probable error is referred to here as being the more familiar quantity.

where $\bar{\xi}$ is the mean, α and β are the deviations from that mean produced by the causes A and B, and ξ' is the random deviation. Then, for a large sample of N readings, the total sum of the squares of the deviations from the mean is $\Sigma(x-\bar{\xi})^2$ and it can be shown that $\Sigma(x-\bar{\xi})^2 \to \Sigma\alpha^2+\Sigma\beta^2+\Sigma\xi'^2$, as N becomes indefinitely large, or, dividing by N, the size of the sample,

$$\sigma_x^2=\sigma_\alpha^2+\sigma_\beta^2+\sigma_{\xi'}^2$$

where σ is the standard deviation of the quantity denoted by the suffix, and σ^2 is the *mean variance*. That is to say, the total variance of x is equal to the sum of the variances due to the associated causes and the residual random variance. If any cause has an important effect on x then its variance will make up a large part of the total; if its effect is very small, the corresponding variance will be a small proportion of the whole.

The following examples illustrate methods of analysing the variability of a quantity into parts associated with the various causes.

Example I

The data for the first example are given in Table I, and are the products, mean lea strengths in pounds multiplied by mean counts, observed on 12 or 13 leas of cotton yarn. Three batches were spun from each of four rovings, which were taken from four separate spindles of the roving frame. In this example it will be assumed that the batches were spun under otherwise identical conditions.

Table I
Products, Lea Strength × Counts

Spindle	1	2	3	4
Batch A	1577	1690	1800	1642
,, B	1535	1640	1783	1621
,, C	1592	1652	1810	1663
Means	1568·00	1660·67	1797·67	1642·00

Grand Mean = 1667·08

The total variations may be divided into two portions, those between spindles and those between readings on the same spindle. The reality of such a partition is obvious from a cursory glance at the table. Spindle 1 always gives the lowest product, and spindle 3 the highest; the differences between the spindle means are greater in magnitude than those between the products of the same spindle.

This is therefore a simple example, in which the deviations are produced by a single cause (the spindle effect) and random errors. Any individual measurement on yarn from the t th. spindle is given by

$$x=\bar{\xi}+\alpha_t+\xi'$$

where $\bar{\xi}$ is the grand mean, α_t is the deviation of the t th. spindle mean from the grand mean, and ξ' is the residual, or random deviation—all being accurate values for the infinite population of all the readings that could possibly be taken.*

But these quantities are not known, so that values obtained from the sample must be substituted; hence

$$x=\bar{x}+a_t+x'$$

where $\bar{x}$ is the grand mean, a_t is the deviation of the t th. spindle mean from that grand mean, and x' is the residual deviation of the reading from its spindle mean—all found from the sample.*

Then the sum of the squares of the deviations is

$$\Sigma(x-\bar{x})^2=\Sigma a_t^2+\Sigma x'^2=3\sum_t a_t^2+\Sigma x'^2$$

where Σ is the summation over all readings and $\sum_t$ is the summation over all spindles (there are three readings from each spindle). These are the "Sums of Squares" of Table II, the equation for this example being—

$$86{,}983{\cdot}0=82{,}619{\cdot}5+4{,}363{\cdot}3$$

Table II
Analysis of Variance

Source of Variations	Sum of Squares	Degrees of Freedom	Mean Variance
Between spindles	82,619·5	3	27,539·8
Residual (within spindles) ...	4,363·3	8	545·4
Total	86,983·0	11	—

The sums of squares arising from the two separated sources must together equal the total; this may be used as a check on the accuracy of the arithmetic.† The importance of the spindle variations is now evident; they account for 95% of the total sum of squares. But these figures are not strictly comparable, since the sums of squares are those of four *inter-* and twelve *intra*-spindle deviations; it is therefore necessary to estimate the mean variances.

The "best" estimate of the mean variance is obtained by dividing the sum of squares, *not* by the number of observations from which it is calculated, but by the number of "degrees of freedom."[3]

The number of *degrees of freedom* is the number of deviations, less the number of means (or other constants) used in measuring them, provided that these constants are determined from the data. Thus, there are four spindle means, and their deviations are measured from one grand mean, giving three degrees of freedom. Similarly, for the total sum of squares, twelve deviations from the grand mean are taken, giving eleven degrees of freedom. For the residual variations within the spindles twelve deviations are measured from four spindle means, giving eight degrees of freedom. The degrees of freedom of the two parts must also add up to give the total.

The mean variances given in Table II are thus estimates based on 3, 8, and 11 degrees of freedom, and are directly comparable. The mean variance of residual deviations is the "best" estimate of the square of their standard deviation, while that between spindles is subject to two contributions. (1) If there were no real spindle effect there would still be slight variations between spindle means, since each is the mean of only three observations, and so is subject to the random errors due to intra-spindle variations;

* Greek letters are used to denote the true values of the infinite population, and Italic letters denote the corresponding estimates obtained from the sample.

† The error of 0·2 in this example is due to the fact that an insufficient number of decimal places has been used.

(2) to this may be added the variance due to the spindle effect. That is to say, the analysis of Table II has not completely freed the ***inter-spindle*** variance from the effects of the residual deviations; the ***residual*** variance, however, is homogeneous. If the second contribution above were zero, the two mean variances of Table II would be nearly equal, as is shown below.

Suppose there are n readings taken on each of an indefinitely large number of spindles, and let σ_a be the standard deviation of spindle variations, and $\sigma_{\xi'}$ be the standard deviation of residual variations within spindles. Then, the mean *intra*-spindle variance, $v_{\xi'}^2=\sigma_{\xi'}^2$, and the mean *inter*-spindle variance,

$$v_a^2=n(\sigma_a^2+\sigma_{\xi'}^2/n)=n\sigma_a^2+\sigma_{\xi'}^2$$

The $\sigma_{\xi'}^2/n$ of the above equation is the square of the standard deviation of spindle means due to random errors (i.e. the square of the "standard error"). From the above equations $\sigma_a^2=(v_a^2-v_{\xi'}^2)/n$ so that if $\sigma_a^2=0$, $v_{\xi'}^2=v_a^2$.

Here again it should be noted that these equations apply to the infinite population of readings, and that with finite samples the variances would be expected to be *nearly* equal, rather than *exactly* equal, if the spindle effect were absent.

In this example the mean variance between spindles is so much larger than the residual that a real and considerable spindle effect is evident. The estimated standard deviation of the *intra*-spindle differences is $\sqrt{545{\cdot}4}=23{\cdot}4$, and that of the *inter*-spindle differences is $\sqrt{(27{,}539{\cdot}8-545{\cdot}4)/3}=94{\cdot}9$.

Example II

The data for this example were provided by a series of 3,720 single-thread breaking load tests of cotton yarn from 48 cops, done on the Moscrop machine. The complete data cannot be given, but the variances are analysed into two portions in Table III. The process of analysis was practically the same as in the previous example, except that to save labour the data were grouped.* It is instructive to see how the numbers of degrees of freedom arise here. For the total variance, 3,720 deviations were measured from one (the grand) mean, giving 3,719 degrees of freedom; for the residual, 3,720 deviations were measured from 48 cop means, giving 3,672 degrees; and for the variance between cops, the 48 cop means were measured as deviations from the grand mean, giving 47 degrees of freedom. The mean variances show that the cop variations are considerably greater than can be attributed to random errors.

The standard deviation of residual variations is $\sqrt{0{\cdot}946}=0{\cdot}97$, and that of cop variations is $\sqrt{(16{\cdot}285-0{\cdot}946)/77{\cdot}5}=0{\cdot}44$ (there are on the average 77·5 readings per cop).

Table III—Single Thread Breaking loads in ozs.

Source of Variations	Sum of Squares	Degrees of Freedom	Mean Variance
Between cops	765·39	47	16·285
Residual (within cop)	3,474·62	3,672	0·946
Total	4,240·01	3,719	1,140

* Sheppard's corrections for grouping were not applied.

II—APPLICATION TO THE THEORY OF ERRORS

In order to find the effect of varying conditions on any property of textiles (say the effect of a change of humidity on the breaking strength of yarn), it is usual to take samples and to compare the means. The accuracy of the difference is expressed by a probable error, which, as has been stated, is a consequence of variations in the readings and is calculated from a measure of them—usually the standard deviation.* In order that the probable error so found may be legitimately used two conditions must be satisfied—(1) It must be calculated from the variations that are being sampled to give the measured difference, and (2) the individuals of the sample must be random and independent. These conditions are obvious, but where the variability is made up of several parts, complications arise. Consider Example II above.

If it is desired to compare the mean strength of this yarn with that of another spun under independent conditions, and if the 48 cops may be regarded as selected at random from the whole bulk, then the true probable error of the mean is found by calculating the probable error of the grand mean of the 48 cop means in the usual manner. Such a probable error is obtained from the variance of the first row of Table III, and it equals $\pm 0{\cdot}045$. A common mistake is to lump the individual readings to form a composite frequency curve, and to find the probable error of the mean from this. Such a course assumes that all sources of variation have been sampled 3,720 times, and neglects the fact that the very important cop variation has only been sampled 48 times. Consequently, it gives an underestimate of the probable error—$\pm 0{\cdot}012$—which is little more than a quarter of the true value.

For some purposes, however, it is possible to eliminate the cop differences from a comparison. For example, in order to compare the strengths when tested at 60% and 70% relative humidity, 40 specimens (say) from each cop can be broken at each humidity. Or, if it is required to find the effect of humidity during spinning on the strength of the yarn, enough for 40 tests (say) with an allowance for waste can be spun at one humidity, and then, on the same cops, a similar length of yarn can be spun at the other humidity. These cops can then be conditioned and tested together. Such methods eliminate the cop variations from the comparison, and the probable error is calculated on the small residual variance of Table III; the result for this sample of 3,720 is $\pm 0{\cdot}011$. Two samples so chosen give as accurate a comparison as two of 16 times the size chosen at random from different cops. Here, however, a word of caution is necessary. It has been assumed that the variations within a cop are random—that the residual variance is homogeneous; but that may not be so. There may be "long-wave" variations, and the yarn may get progressively weaker (or stronger) in the lower layers of the cops. To overcome such a source of error the tests could be divided into two series; in one series the 60% R.H. tests could be done on yarn taken from the top of the cop and the 70% tests on yarn from the lower layers, and *vice versa* in the other series.

Similarly, if different spinning systems are to be compared, by selecting rovings from the same spindles (Example I) the enormous spindle-effect can be eliminated, and the probable errors calculated on the smaller residual

* Since the mean variance is an estimate of the square of the standard deviation, the probable error of the mean of a sample of n is

$$\text{P.E.} = 0{\cdot}6745\ \sqrt{\textit{mean variance}/n}$$

variations within spindles—the practical result being to decrease the number of tests necessary to obtain a given precision.

It is thus often possible to eliminate large variations from comparisons, and if the arrangement of the experiments is properly balanced, and, within the restrictions imposed, *random*, it is usually possible to analyse the variances, and to estimate the improved precision. Of course, it is not always necessary to do this so elaborately as has been done thus far. In the humidity tests on cops of yarn, for instance, the mean strength of the 40 tests done at each humidity on each of 20 cops can be found, and thence the differences between *corresponding* cop means; the mean difference and its probable error can then be calculated from those 20 differences.* There are other examples in the textile literature in which these large variations are eliminated.

Midgley and Peirce[5] give one. They form "cut-skein" samples of yarn by wrapping, say, 30 turns on a wrap-reel, fixing them by means of strips of plaster at opposite ends of a diameter, and cutting through the plaster. Thus, "cut-skeins" are samples of 30 threads, the corresponding ones in each half being adjacent lengths of yarn in the cop, so that corresponding pairs of samples tend to be much more alike than random pairs. In one control ballistic test on 50 pairs, they found the means of the two series of halves to be $217{\cdot}62 \pm 1{\cdot}88$ and $217{\cdot}74 \pm 1{\cdot}99$ work units. The probable error of the difference in means as found from the probable errors of the separate means is $\pm\sqrt{1{\cdot}88^2+1{\cdot}99^2} = \pm 2{\cdot}74$; this is the probable error of the difference between pairs taken quite at random. If the 50 differences are found between corresponding pairs, and the probable error of the mean difference calculated, it is $\pm 0{\cdot}71$.

Similarly, in finding the effect of humidity on the breaking loads of single cotton hairs, Mann[4] did all he could to ensure that the samples for the five humidities should be as similar as possible by counting out 25 bundles of 40 hairs, weighing them, and arranging them in five groups of 200 so as to make the total weight of each lot the same. As he realises, such a procedure, if effective, throws much of the total variability within the group, so that the probable errors of the group means as found from those *intra*-group variations over-estimate the *inter*-group errors. His data, as published, do not permit of an analysis of the variances, or an estimate of the true errors of sampling.

III—FURTHER USES AND EXAMPLES OF THE ANALYSIS OF VARIANCE

The analysis of variance is useful apart from the help it gives in finding probable errors. The existence of large sources of variability is not always so obvious as is that of the "spindle-effect" of Example I, and in such circumstances an analysis shows up and establishes the reality of the source. The knowledge of the existence and importance of such effects is of itself often useful.

It is often necessary, moreover, to divide the variance of any quantity into more than two parts. Here the analysis is more complex, but the interpretation of the mean variances is always the same. When comparing the effects of more than two sets of conditions on some property, say, of yarns, the use of probable errors as tests of the significance of the effects is clumsy.

* On small samples of less than about 20 the simple criterion that differences greater than three times the probable error are real, is unreliable. "Student's" more exact tests, similar in principle, but involving the exact frequency distributions of the ratio, mean difference ÷ standard error, are given in Fisher's book.[3].

It is better to regard the various conditions or treatments as another source of variability and to give it a line in a table of analysis. The mean variance for treatments can then be compared with the appropriate residual, and if it is significantly greater, the effect of the treatments is regarded as real.

Example III

The data for this example are those already given for Example I, but there is now supplied the additional information that the batches A, B, and C are the results of different weights placed on the rollers (in the first example this was ignored). The variance will now be further analysed to test the effect of the weighting.

For an indefinitely large number of readings, taken from an indefinitely large number of spindles and batches, the first equation of Ex. I, p. T106 becomes

$$x_{tu}=\bar{\xi}+\alpha_t+\beta_u+\xi'_{tu}$$

where x_{tu} is the reading taken from the t th. spindle and u th. batch

$\bar{\xi}$ is the grand mean,

α_t is the deviation of the t th. spindle mean from the grand mean

β_u ,, ,, ,, u th. batch ,, ,, ,,

and ξ'_{tu} is the residual.

Again none of these quantities is known and values obtained from the sample must be substituted, whence

$$x_{tu}=\bar{x}+a_t+b_u+x'_{tu}$$

and $\sum_{tu}(x-\bar{x})^2=m\sum_t a_t^2+n\sum_u b_u^2+\sum_{tu}x'_{tu}$,

where $\sum_{tu}$ means sum for all values of t and u

$\sum_t$,, ,, ,, t, and so on,

n is the number of spindles and

m is the number of batches.

The quantities $\sum_{tu}(x-\bar{x})^2$, $m\sum a_t^2$, $n\sum_u b_u^2$ and $\sum_{tu}x'_{tu}$ are the sums of squares given in Table IV. It must be noticed that since all the batches are equally represented in each spindle, the spindle deviations, a, are quite independent of batch variations. Similarly, the batch deviations, b, are independent of the spindle variations.

From these quantities are obtained estimates

$S_a^2=m\sum_t a_t^2/(n-1)$ based on $n-1$ degrees of freedom, of the mean variance,

$$v_a^2=m\sigma_\alpha^2+\sigma_{\xi'}^2 ,$$

$S_b^2=n\sum_u b_u^2/(m-1)$ based on $m-1$ degrees of freedom, of the mean variance,

$$v_\beta^2=n\sigma_\beta^2+\sigma_{\xi'}^2 ,\text{ and}$$

$S_{x'}^2=\sum_{tu}x_{tu}'^2/(m-1)(n-1)$ based on $(m-1)(n-1)$ degrees of freedom, of the mean variance, $\sigma_{\xi'}^2$, where σ_α, σ_β, and $\sigma_{\xi'}$ are the standard deviations of spindle means, batch means, and random deviations in the infinite population of spindles and batches. These estimates of mean variance are given in Table IV.

If there is no "spindle" effect, $\sigma_\alpha=0$, and $\sigma_a^2=\sigma_{\xi'}^2$. Similarly, if there is no batch effect, $\sigma_\beta=0$ and $\sigma_b^2=\sigma_{\xi'}^2$. This is the basis on which the existence of either effect is tested. But only the estimates, S_a^2, S^2, and $S_{x'}^2$, which are subject to errors, are available; hence, since these errors may be

responsible for the differences between the estimates, it is necessary to test the differences for significance before they can be used to establish the reality of an effect. This test has been worked out by Fisher[3] and involves the finding of a quantity z, equal to half the difference of the natural logarithms of the variances; for example

$$z=\tfrac{1}{2}(\log_e S_a^2-\log_e S_x^2).$$

Then, the numbers of degrees of freedom on which the estimates are based being known, the probability that such a value of z could arise from random errors is found from the Tables.[3] If this probability is below 0·05 the difference is formally regarded as significant, and pointing to a real effect.

Table IV

Further Analysis of Variance of Table II

Source of Variations	Sum of Squares	Degrees of Freedom	Mean Variance
Between spindles	82,619·5	3	27,539·8
Between batches	3,000·8	2	1,500·4
Residual	1,362·7	6	227·1
Total	86,983·0	11	—

To test the significance of the batch effect for Table IV

$$z=\tfrac{1}{2}(\log_e 1{,}500{\cdot}4-\log_e 227{\cdot}1)=0{\cdot}94.$$

According to Fisher's tables, for two and six degrees of freedom z must equal 0·82 to lie on the 0·05 level of significance and 1·20 to lie on the 0·01 level—so the differences between batches are probably real. The z for the difference between spindle and residual variances is 2·40, while for three and six degrees of freedom, a z of 1·14 lies on the 0·01 level of significance—the reality of the spindle effect is amply proved.

Other examples of more complex analyses follow.

Example IV

The data are daily outputs in weaving. Five weavers each wove for 12 weeks of five days each, giving 300 readings altogether. The weavers were all weaving in the same place at the same time. The total variance is divided into three portions representing variations between the means for the days of the week, variations between the weekly means, and the residual. This analysis was performed for each weaver separately, and the second and third columns of the five tables so formed were added to give the corresponding columns of Table V.

In the notation of the equations on p. T111 for each individual weaver, $\bar{x}$ is the mean output, a_t the deviation of the mean output for the t th. day of the week, and b_u the deviation of the u th. weekly mean, $n=5$ and $m=12$, giving 4, 11, and 44 degrees of freedom for the three constituent variances, or 20, 55, and 220 for the five weavers combined. Again, the arrangement is so balanced that the weekly means are independent of the day-of-week variations and the daily means are independent of the weekly variations, that is to say, the a's and the b's are independent.

The column of means of Table V shows that the day-of-week variance is only slightly (and insignificantly) greater than the residual. It is concluded, therefore, that on the data provided, no consistent differences are maintained

between outputs on different days of the week. The variance for weekly means, however, is significantly greater than the residual, so that the weekly variations are greater than random changes can explain.

It is instructive to analyse this weekly variance further.

Table V
Analysis of Variance of Outputs

Source of Variations	Sum of Squares	Degrees of Freedom	Mean Variance
Day of week	29,966·5	20	1498·3
Weekly means	220,370·5	55	4006·7
Residual	281,569,5	220	1279·9
Total	531,906·5	295	—

Further Analysis of Variance of Weekly Means

Common trend	64,987·3	11	5907·9
Individual differences in trend	155,382·2	44	3531·4
Total	220,370·5	55	—

Table VI
Weekly Mean Output in Weaving (in picks per loom per day÷100)

Week Ending	Weaver A	B	C	D	E	Mean for all Weavers
April 1	870·2	892·8	816·2	852·8	791·0	844·60
,, 8	848·0	883·0	820·0	844·0	871·8	853·36
,, 29	845·0	773·6	854·4	809·0	860·6	828·52
May 6	841·2	860·6	871·2	843·4	859·2	855·12
,, 13	855·0	857·0	869·6	821·2	779·2	836·40
,, 20	878·4	877·0	861·2	888·6	841·6	865·20
,, 27	882·8	872·0	835·0	867·8	842·2	868·68
June 3	870·8	803·2	846·8	911·4	820·6	843·32
,, 17	854·0	814·8	808·0	875·2	851·8	840·52
,, 24	863·0	858·6	861·4	874·0	834·0	856·88
July 1	884·6	887·8	833·8	867·4	834·8	865·92
,, 8	907·0	868·8	871·0	900·0	861·8	881·72
Means	866·67	854·10	845·72	862·90	837·38	853·35

The 12 weekly means for each weaver are given in Table VI, and may be taken to represent five separate secular trends; it is desired to ascertain how far these trends may be represented by one trend common to all weavers. The mean weekly outputs for all weavers, given in the last column of Table VI, represent the common trend. Then the variance of the 60 weekly means can be analysed into three parts, (1) a part associated with differences between weavers, which are not being considered, and which are eliminated by measuring the weekly means as deviations from the weaver means, (2) a part associated with the 12 weekly means for all weavers—the common trend, and (3) a residual of individual weaver differences in trend. That is to say, if b_{tu} is the t th. weekly mean for the u th. weaver, and b_t the t th. weekly mean for all weavers, both measured from the appropriate weaver means, $b_{tu}=b_t+b'_{tu}$ where b'_{tu} is the residual deviation, and $\sum_{tu} b_{tu}^2=\sum_t b_t^2+\sum_{tu} b_{tu}'^2$. The first term is

the sum of squares of the weekly mean deviations from the weaver means

$$[(870{\cdot}2-866{\cdot}7)^2+(848{\cdot}0-866{\cdot}7)^2+\ldots\ldots+(892{\cdot}8-854{\cdot}10)^2+\ldots\ldots]$$
$$=44{,}074{\cdot}10.$$

This must be multiplied by 5, for inclusion in Table V, since each reading is the mean of five daily readings, and becomes 220,370·5. The second term is the sum of squares given by the common trend, and amounts to

$$5[(844{\cdot}60-853{\cdot}35)^2+(853{\cdot}36-853{\cdot}35)^2+\ldots\ldots]=12{,}997{\cdot}46;$$

this also must be multiplied by 5 for inclusion in Table V (and then equals 64,987·3). The third term, the sum of squares given by the individual weaver differences in trend, may be obtained by subtraction, or by adding the separate terms

$$[\{(870{\cdot}2-866{\cdot}67)-(844{\cdot}60-853{\cdot}35)\}^2+\{(848{\cdot}0-866{\cdot}67)-(853{\cdot}36-853{\cdot}35)\}^2+\ldots\ldots+\{(892{\cdot}8-854{\cdot}10)-(844{\cdot}60-853{\cdot}35)\}^2+\ldots\ldots]$$

and multiplying by 5, as before.

The mean variance for the common trend (5907·9) is significantly greater than that for individual differences in trend (3531·4), but the latter is still significantly greater than the residual 1279·9 from the top of Table V. Thus there are superimposed the results of three effects, (1) weekly variations common to all weavers, (2) individual weaver differences in trend from the common trend, and (3) random daily variations.

Consequently, if the effect of some change in weaving conditions on output were to be found, and the conditions could be changed only once a week, the week to week variations would be added to the random errors, and could be only partially eliminated by keeping a few "control" weavers under constant conditions.

Example V

The data are mean warp breakage rates (i.e. the number of breaks per 10,000 picks) obtained during the weaving of 40 beams on 12 looms attended by four weavers. Three possible sources may go to make up the total variability, (1) weavers may differ in efficiency, so that one may consistently have more breaks than another, (2) some looms may be consistently more destructive on warps than others, and (3) there will be residual beam variations due to inherent differences in the beams, their yarn, sizing, and gaiting up. From the point of view of the present analysis, the third source may be regarded as random. This example must be worked out a little differently from the previous examples, since there was not an equal number of beams on each loom. Moreover, since different weavers could not work on the same looms, an *omnibus* analysis into the three portions is not possible—it must be done in two stages.

The raw data are given in Table VII, and the analysis of variance in Table VIII. The deviations of the individual readings from the loom means are subject only to the third source of variation, and the sum of their squares is

$$[(0{\cdot}73-1{\cdot}364)^2+(1{\cdot}11-1{\cdot}364)^2+\ldots\ldots+(0{\cdot}99-1{\cdot}122)^2+\ldots\ldots]=7{\cdot}12,$$

and is given in the second row of Table VIII. There are 40 readings, and the deviations are measured from 12 loom means, giving 28 degrees of freedom. The deviations for the loom variance are obtained by subtracting the weaver means from the loom means. The sum of squares, duly weighted, is

$$[5(1{\cdot}364-1{\cdot}208)^2+5(1{\cdot}122-1{\cdot}208)^2+\ldots\ldots+4(1{\cdot}850-2{\cdot}086)^2+\ldots\ldots]=0{\cdot}87.$$

There are 12 loom means measured as deviations from four weaver means, giving eight degrees of freedom. The first total of Table VIII is obtained

from the individual deviations from the weaver means, and is

$$[(0{\cdot}73-1{\cdot}208)^2+(1{\cdot}11-1{\cdot}208)^2+\ldots\ldots+(1{\cdot}23-2{\cdot}086)^2+\ldots\ldots]=7{\cdot}99,$$

with $(40-4)=36$ degrees of freedom.

The mean variance for looms is less than the residual (the difference is insignificant), indicating the absence of any real loom effect. Consequently the total variations about the weaver means may be regarded as homogeneous and random, and may be compared with those between weavers. This analysis is given in the lower half of Table VIII.

Table VII

Mean Warp Breaks per 10,000 Picks

Loom No.	Beam Means					Loom Means	Weaver Means
1	0·73	1·11	1·30	1·90	1·78	1·364	
2	0·99	0·74	0·71	1·30	1·87	1·122	1·208
3	0·68	1·39	—	—	—	1·035	
4	1·23	2·05	2·20	1·92	—	1·850	
5	2·10	1·35	3·22	2·34	—	2·252	2·086
6	1·58	2·28	2·68	—	—	2·180	
7	2·89	1·37	—	—	—	2·130	
8	1·71	2·00	2·21	—	—	1·973	2·091
9	2·10	2·29	2·16	—	—	2·183	
10	1·48	1·30	1·00	—	—	1·260	
11	1·39	0·86	1·00	—	—	1·083	1·271
12	1·66	1·84	0·91	—	—	1·470	
						Grand Mean = 1·640	

Table VIII

Analysis of Variance of Warp Breaks

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Variance
Looms	0·87	8	0·11
Residual (beams)	7·12	28	0·25
Total	7·99	36	—
Weavers	7·28	3	2·43
Residual (looms+beams) ...	7·99	36	0·22
Total	15·27	39	—

The "weaver" sum of squares is

$$[12(1{\cdot}208-1{\cdot}640)^2+11(2{\cdot}086-1{\cdot}640)^2+\ldots\ldots]=7{\cdot}28,$$

with three degrees of freedom, the second residual is the "total" of the first part of the table, and the final total is

$$[(0{\cdot}73-1{\cdot}640)^2+(1{\cdot}11-1{\cdot}640)^2+\ldots\ldots\ldots]=15{\cdot}27,$$

with 39 degrees of freedom. The analysis shows that here there are consistent differences in warp breakage rates associated with weavers.

In all the foregoing examples, the deviations produced by the causes (A and B of p. T106) have been expressed by a series of group means. This, however, is not the only method of expression. The use of the correlation coefficient is a good example of a different method. Implicitly, when correlating two quantities (x and y), the "best" straight line of the form $(y-\bar{y})=a(x-\bar{x})$, giving y in terms of x ($\bar{x}$ and $\bar{y}$ are means) is found. Then, if r is the correlation coefficient, and σ_y is the standard deviation of y, the square of the standard deviation representing the scatter of y about the straight line is $\sigma_y^2-r^2\sigma_y^2$. The total variance of y (σ_y^2) is thus divided into two parts, one associated with the relation, expressed by a straight line, to x ($r^2\sigma_y^2$), and the other with the deviations from that line, ($\sigma_y^2-r^2\sigma_y^2$).

Similarly, a curve involving any function of x may be fitted, and the variance divided into two parts—one associated with the curve and the other with random deviations from it. The number of "degrees of freedom" of the random deviations is here the number of observations less the number of constants found from the data (i.e. two for linear regression).* In this way it is often convenient to analyse variations in yarn qualities into "long-wave" effects and random deviations.

IV—CLOTH SAMPLING

The question of the sampling of cloths is but a particular application of the foregoing principles and methods. It is analogous to the problem of arranging experimental plots for agricultural field trials, and the following discussion describes the technique that has been worked out in this connection.

If the tests are merely being made to obtain the average of some property (say breaking strength) of a batch of cloth, then it is well to take the samples at random from as large an area as possible. But much textile research is concerned with varying the conditions of testing, or the treatment of the cloth, in order to find their effect. In such circumstances, it is to be expected that there will be systematic regional variations in strength, on which will be superimposed the smaller random variations, and that by a suitable arrangement, only these random variations will contribute to the inaccuracy of the comparisons. Thus, Turner[7] tested strips of cloth at six humidities (A, B, C, D, E, F) and for his warp-way tests adopted the systematic arrangement—

```
                 Weft-
        | A B C D E F A B C D
Warp    | E F A B C D E F A B
        ↓ C D E F A B C D and so on
```

A long discussion of the principles and methods of such arrangements (particularly of "chess board" sampling) is given by Engledow and Yule[2].

These methods, however, violate one of the conditions that must be satisfied if reliable estimates of probable errors and variances are to be made—the treatments are not randomly distributed within the restrictions imposed to eliminate regional variations. Some restricted random arrangements will now be discussed.

* In order that the tests for significance of differences in variance may be valid, the fitted curves must satisfy Fisher's criterion of *efficiency*.[3] The method of "Least Squares" gives an *efficient* fit.

Restricted Random Arrangements

Let it be assumed that five treatments (say to test the strength of cloth at five different humidities) are to be compared. The simplest arrangement would be to take groups of five adjacent test-pieces, and to distribute the treatments at random, but with one treatment in each group. Then the total variance could be straightforwardly analysed into three portions, (1) variance between groups, (2) variance between treatments, and (3) residual random variance. Such an arrangement would be suitable, for example, when testing a cloth weft-way, if only two test-pieces could be obtained from the width of the cloth. Fig. 1 illustrates a possible example (the treatments are given letters A, B, C, D, and E) in which the groups are separated by heavier lines. In order to avoid confining attention to some small area of cloth which may be abnormal in its reaction to the treatments, these blocks of five could be taken from scattered parts of a bulk, without increasing the residual variance.

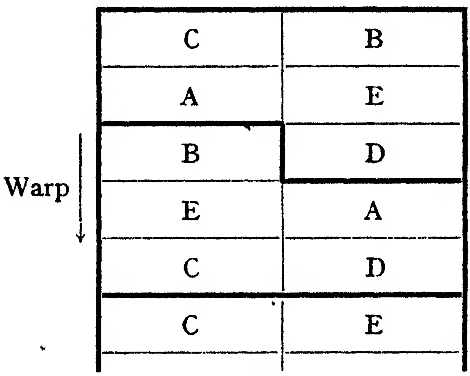

FIG. 1

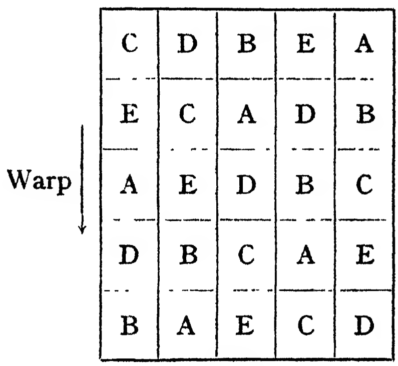

FIG. 2

It is often possible to combine a group arrangement with what Fisher[3] calls a Latin square. If five treatments are to be compared, then to form a Latin square a block of $5 \times 5 = 25$ specimens must be taken, and the treatments distributed at random within the block, with the restriction that each treatment must occur once in each row, and once in each column. Fig. 2 illustrates a suitable arrangement. Several such blocks can be taken from a large area of cloth. Such an arrangement is particularly suitable to warp-way breaking tests, when five or more specimens can be taken across the width. For the weft-way tests of Fig. 1 it would be impossible.

If several blocks are thus taken, the total can first be divided into variance between block means (weighted with the number of readings per block), and variance within the blocks. Since each block provides five readings for each treatment, the differences between the block means are independent of treatment differences. The variance within blocks may now be further subdivided into four portions. (1) Each row provides one reading for each treatment, and one for each column, so that the sum of squares of the deviations of the row means measures the variance between the rows; (2) each column mean is obtained from one reading for each treatment and one for each row, so that the variations of the column means are independent of row and treatment variations, and the column variance may be obtained in the same way as the row variance, (3) the differences in treatment means being independent of rows and columns, the treatment variance may be

similarly obtained; and finally, (4) the residual variance due to random deviations is the remainder. The treatment differences are common to all blocks, and however many blocks are taken, there are only four degrees of freedom, but the column and row means must be found for each block separately, so that for columns and rows the number of degrees of freedom is four times the number of blocks. The process can be expressed by a series of equations like those of p. T111, and a scheme for computing the quantities is given below.

If x_1, x_2......x_N are the individual readings,
T the grand total, X the grand mean, N the total number of readings,
T_B the block totals, X_B the block means, N_B the number of readings in each block,
*T_R the row totals, X_R the row means, N_R the number of readings in each row,
*T_C the column totals, X_C the column means, N_C the number of readings in each column,
T_T the treatment totals, X_T the treatment means, N_T the number of readings in each treatment,
and n_B, n_R, n_C, n_T the numbers of blocks, rows, columns, and treatments, so that $n_B N_B = n_R N_R = n_C N_C = n_T N_T = N$, then the various terms in the table of analysis of variance may be written—

Variance due to	Sum of Squares	Degrees of Freedom
Blocks	$\sum_B T_B X_B - TX$	$n_B - 1$
Rows	$\sum_R T_R X_R - \sum_B T_B X_B$	$n_R - n_B$
Columns	$\sum_C T_C X_C - \sum_B T_B X_B$	$n_C - n_B$
Treatments	$\sum_T T_T X_T - TX$	$n_T - 1$
Total	$\Sigma x^2 - TX$	$N - 1$

The residual is found by subtracting the first four terms from the total. With little trouble all the terms can be calculated to sufficient decimal places.

Example VI

A fabric was tested warp-way on the ballistic machine. There were five different treatments arranged in four 5×5 Latin squares, giving 100 test-pieces altogether. The variance is analysed in Table IX. It is to be noted

Table IX
Analysis of Variance

Source of Variations	Sum of Squares	Degrees of Freedom	Mean Variance
Rows	1410·98	16	88·2
Columns	674·78	16	42·2
Treatments	74·41	4	18·6
Residual	1724·96	60	28·7
Total within blocks	3885·63	96	40·5
Between blocks	299·51	3	99·8
Grand total	4184·64	99	42·3

* The row and column means must be found separately for each block. Usually, for Latin squares, $n_T n_B = n_R = n_C$.

first that the mean variance due to treatments is no greater than the residual—indeed it is less, although the difference is not significant. Hence it may be assumed that the differences of treatment have had no measurable effect on the work of rupture of the cloth. The variances for rows and blocks are significantly greater than the residual, while the significance of the difference between the variance for columns and the residual is doubtful. The grand total variance includes the effects of the treatments, but since the treatments have no effect, the total variance may be compared with the residual to appreciate the increased accuracy resulting from this arrangement. If the five treatments had been taken at random from the whole area of cloth the sampling errors of the differences would have been measured on the mean variance of 42·3, while with the Latin square arrangement they are measured on 28·7. That is to say, in order to establish such differences a sample of 29 so arranged is as good as one of 40 taken purely at random. Such an expression of systematic variations seems to be particularly suitable for cloth testing, where rows can be taken across the warp, and columns along its length. It is a matter for further investigation what size of blocks is suitable, if more than five treatments are being compared. For example, if nine treatments are being compared it may be better to take two series of 5×5 blocks, in which one of the treatments always appears as a control, than to take 9×9 blocks. This would be necessary if the "contours" of strength did not extend the length or width of nine test-pieces. A number of control tests, done after the manner of Example VII for blocks of different sizes would decide such a point. Examples have been found in which the Latin square arrangement is very little superior to the random (for instance, for a very different cloth the variances were 3·1 and 3·4), while in others the advantage is much more marked (In one example, for a different kind of test, the variances were 67·8 and 134·1 for the Latin square and random arrangements).

There are disadvantages to the method, however, and precautions are necessary. If one test piece is lost or spoilt, the whole square in which it is placed must be discarded. On the other hand, with the smaller groups of five or so, or with arrangements in which neighbouring pairs are compared (as in the "chess board" arrangement), if one specimen is lost only three or four others need be discarded in consequence. Mistakes are more liable to be made in random than in systematic arrangements, but within the restrictions imposed randomness is essential if accurate estimates of the errors of sampling are to be made; regular arrangements of treatments may often coincide with some uneliminated trend in the cloth. This consideration is particularly important in textile testing, where many specimens are used, and the estimates of means and variabilities tend to be more exact.

There will often be technical difficulties to the use of any of the proposed arrangements. The test-pieces are usually comparatively small and it is not always possible to vary the treatments over such small areas. If the pieces can be cut up and sorted, and the treatments be carried out on them, or if the testing conditions only are being varied, the suggested arrangements are possible. On the other hand, many processes (like schreinering) can only be carried out satisfactorily on larger pieces of cloth. For such processes the treatments should be repeated more than once, if possible, and the principles of sampling and analysis of variance applied to the larger pieces.

V—CORRELATION

The degree of association between two quantities in any population is often expressed as a correlation coefficient, and the value of this is often taken to indicate the presence or absence of some causal relationship between the two quantities. When the variations are complex, however, such an interpretation is beset with many pitfalls. Consider, for example, Lancashire's export of cotton piece goods and the country's consumption of bananas for 50 years before the war. Both were tending to increase, and so there would certainly be a positive correlation between these two quantities. Yet no one has suggested that the way to restore Lancashire's trade is to induce the country to eat more bananas. The truth is, there is no causal relationship and the association is an accidental one in time. The time-effect can be eliminated by fitting smooth curves to the two series of readings, and then correlating the deviations from these curves. Only after such effects have been eliminated (that is to say, the total variability analysed), and the correlation is between homogeneous residuals, can it be regarded as pointing to a causal relationship. The process of deciding what sources of variability are likely to exist in any particular problem is somewhat intuitive, and depends upon a knowledge of the technical aspects of the case. When the sources have been determined, some suitable mode of expression of the trends due to them must be found. An example of some practical importance is here given.

Example VII—The Correlation of Warp Breaks in Weaving with Temperature and Humidity

It is commonly supposed that warp breaks depend to some extent on temperature and humidity. The effect has been tested and measured by the method of correlation. The units used were half-day means for each separate beam, the breakage rate being the ratio $\dfrac{\text{total warp breaks for half-day}}{\text{total picks for half-day}}$ given as breaks per 10,000 picks. Correlation tables were drawn up in which readings from several beams were included. All beams were not included, but only those with nearly the same mean breakage rate. It would not be fair to lump together beams having a low mean with those having a high one, as the latter may possibly be more sensitive to atmospheric changes than the former. Several readings of breakage rates taken on different beams on the same half-day were included and treated as independent, excepting in so far as they were affected by having a common temperature and humidity. Consequently, readings of the temperature and humidity taken on the same half-day were included several times (up to six), so that their distributions are more irregular than would have been expected from the sizes of the totals.

Besides the temperature and humidity, other factors may influence the warp breakage rate. For instance, because of a possible progressive deterioration in the quality of yarn supplied, the later beams in the series may tend to have higher numbers of warp breaks, and if at the same time the weather tends to get hotter, the total effect will be to give a positive bias to the correlation between warp breaks and temperature, which may be sufficient to suggest that high breaks are associated with high temperatures, not because of any causal relationship, but because of an accidental association in time.

It is assumed that all the independent variations that may occur are (1) in the mean breakage rate from beam to beam, (2) from week to week

during the course of weaving a beam, (3) from day to day during the week, (4) through differences between morning and afternoon breakage rates.

In order to express (2), the weaving of each beam was divided into four or five periods, each containing a complete week (excepting Saturday morning), the first and last periods being the first and last weeks, and the others being taken in between. The results of all the other variations were expressed by the appropriate mean of each of the three quantities, breakage rate, temperature, and humidity.

Thus, if a_s is the mean of any one of these quantities for the s th. beam,
b_t is the mean of that quantity for the t th. period,
c_u is the mean of that quantity for the u th. day of the week,
and d_v is the mean of that quantity for the v th. half-day (i.e. morning or afternoon),
all measured from the grand mean $\bar{x}$, then any reading may be expressed as

$$x=\bar{x}+a_s+b_t+c_u+d_v+x',$$

where x' is the residual deviation, which is presumed to be free of any of the four causes of variation.* If these residuals are found for breakage rate, temperature, and humidity, any correlations that exist between them may be taken to measure the causal relationship between the three quantities. Actually, the raw readings are correlated, and the variances analysed according to Fisher's practice[3] to give corrections. If the quantities are

$$x=\bar{x}+a_s+b_t+c_u+d_v+x'$$

$$\text{and}\quad y=\bar{y}+a_s'+b_t'+c_u'+d_v'+y'$$

the correlation coefficient between the residuals is $r=\Sigma x'y'/\sqrt{\Sigma x'^2\Sigma y'^2}$, where Σ is the summation over all observations. It can be shown that

$$\Sigma x'^2=\Sigma(x-\bar{x})^2-\Sigma a_s^2-\Sigma b_t^2-\Sigma c_u^2-\Sigma d_v^2$$

$$\Sigma y'^2=\Sigma(y-\bar{y})^2-\Sigma a_s'^2-\Sigma b_t'^2-\Sigma c_u'^2-\Sigma d_v'^2$$

$$\text{and}\quad \Sigma x'y'=\Sigma(x-\bar{x})\,(y-Y)-\Sigma a_s a_s'-\Sigma b_t b_t'-\Sigma c_u c_u'-\Sigma d_v d_v'.$$

All these quantities are given in Table XV as sums of squares and sums of products for the three quantities, breaks, temperature, and humidity. The sums of squares, of course, measure the variance, while the sums of products give a corresponding quantity which has been named the co-variance. The first quantities on the right-hand side of the equations are obtained from the correlation tables, and would be used in correlating the raw readings. They are given as "Totals" in Table XV. The quantities on the left-hand side are the "Residuals" of that table.

This method of working does not allow more than a linear relationship to be expressed between the three quantities and therefore the range of variation must be taken so small that this approximation is sufficient. If it is suspected that over the whole possible range of temperature and humidity the relationship is not linear, then several smaller ranges about different means may be studied separately in this way, and the several linear equations will together give a good representation of the complete function. The complete data for this example are presented in Tables X–XVI.†

* The values obtained from the sample are being inserted straight away.

† In calculating the constants the grouping was four times as fine as in Tables X–XIII for breakage rates and twice as fine for temperature and humidity. Sheppard's corrections for grouping were not used.

Table X

Correlation Table—Warp Breaks and Temperature

Warp Breaks per 10,000 picks	Temperature °F.											Totals
	60	62	64	66	68	70	72	74	76	78	80	
0·15	—	—	—	2	—	—	—		1	—	—	3
0·55	1	—	1	3	—	1	2	3	2	—	—	13
0·95	—	4	7	5	4	6	4	—	—	—	—	30
1·35	—	1	6	8	5	8	13	7	4	1	—	53
1·75	1	3	7	8	3	16	10	7	3	1	—	59
2·15	—	3	5	9	8	11	11	7	3	6	1	64
2·55	—	4	7	7	5	11	10	6	6	—	—	56
2·95	—	2	—	1	2	14	6	5	7	3	—	40
3·35	1	4	1	—	4	4	3	4	3	2	—	26
3·75	—	1	—	—	1	2	—	—	1	—	—	5
4·15	—	1	1	1	1	1	1	2	1	—	—	9
4·55	—	—	1	—	—	1	—	—	—	—	—	2
Totals	3	23	36	44	33	75	60	41	31	13	1	360

Table XI

Correlation Table—Relative Humidity and Temperature

Relative Humidity per cent.	Temperature °F.											Totals
	60	62	64	66	68	70	72	74	76	78	80	
69	—	—	—	—	—	—	—	—	—	2	—	2
71	—	—	—	—	—	—	—	—	6	7	1	14
73	—	—	—	—	3	18	7	13	15	2	—	58
75	—	4	2	—	6	20	18	11	7	1	—	69
77	—	11	11	14	9	19	26	14	3	1	—	108
79	3	8	14	27	11	10	9	3	—	—	—	85
81	—	—	4	3	3	8	—	—	—	—	—	18
83	—	—	5	—	1	—	—	—	—	—	—	6
Totals	3	23	36	44	33	75	60	41	31	13	1	360

Table XII

Correlation Table—Warp Breaks and Relative Humidity

Warp Breaks per 10,000 picks	Relative Humidity per cent.								Totals
	69	71	73	75	77	79	81	83	
0·15	—	—	1	—	—	2	—	—	3
0·55	—	—	1	2	5	4	1	—	13
0·95	—	—	—	5	9	10	3	3	30
1·35	—	1	6	5	18	16	5	2	53
1·75		1	6	13	17	17	5	—	59
2·15	1	7	12	12	17	13	2	—	64
2·55	—	—	9	17	17	12	1	—	56
2·95	—	4	12	9	11	3	1	—	40
3·35	1	—	7	3	10	4	—	1	26
3·75	—	—	1	2	—	2	—	—	5
4·15	—	1	3	1	3	1	—	—	9
4·55	—	—	—	—	1	1	—	—	2
Totals	2	14	58	69	108	85	18	6	360

Table XIII.—Distribution of Warp Breaks, Temperature, and Humidity among Beams, Periods, Days of the Week, and Half-days

		Beam									Period				Day of Week							
		21/1	27/3	21/2	28/4	45/3	22/1	28/2	46/3	22/2	1	2	3	4	M.	Tu.	W.	Th.	F.	a.m.	p.m.	Totals
Warp Breaks per 10,000 picks	0·15	—	—	—	—	3	—	—	—	—	—	2	—	1	—	1	2	—	—	2	1	3
	0·55	2	1	1	1	4	—	4	—	—	4	3	4	2	6	1	3	1	2	7	6	13
	0·95	7	3	3	3	2	3	4	4	1	9	7	9	5	11	6	5	6	2	24	6	30
	1·35	10	6	5	5	3	8	4	8	4	10	7	17	19	13	16	10	10	4	24	29	53
	1·75	9	5	4	9	6	4	5	9	8	15	15	9	20	17	8	12	9	13	32	27	59
	2·15	4	7	8	9	7	10	8	6	5	13	21	9	21	7	13	8	15	21	32	32	64
	2·55	3	9	8	8	4	6	6	7	5	15	19	17	5	6	11	12	12	15	31	25	56
	2·95	2	4	6	2	7	5	2	6	6	10	11	11	8	6	3	11	12	8	10	30	40
	3·35	1	3	4	2	4	3	5	—	4	7	3	10	6	6	7	5	3	5	11	15	26
	3·75	1	1	—	—	—	—	—	—	3	3	1	1	—	—	3	1	1	—	2	3	5
	4·15	1	1	—	1	—	1	2	—	3	4	—	2	3	—	1	3	3	2	4	5	9
	4·55	—	—	1	—	—	—	—	—	1	—	1	1	—	—	2	—	—	—	1	1	2
Totals ...	...	40	40	40	40	40	40	40	40	40	90	90	90	90	72	72	72	72	72	180	180	360
Temperature °F.	60	—	—	1	—	—	—	1	—	1	—	1	1	1	3	—	—	—	—	3	—	3
	62	4	1	2	—	1	6	6	1	2	11	4	5	3	9	8	—	2	4	23	—	23
	64	8	3	4	1	3	7	3	2	5	16	9	7	4	9	4	4	10	9	36	—	36
	66	5	3	8	—	2	6	8	4	8	8	15	11	10	9	12	12	6	5	41	3	44
	68	3	5	3	4	7	2	3	3	3	3	11	7	12	8	3	9	6	7	31	2	33
	70	11	6	5	10	7	10	8	9	9	26	15	18	16	14	20	9	15	17	29	46	75
	72	6	8	9	6	7	6	5	7	6	14	16	16	14	12	8	16	15	9	16	44	60
	74	3	5	4	10	5	3	5	3	3	4	10	10	17	5	12	5	4	15	1	40	41
	76	—	7	3	5	6	—	1	7	2	5	6	10	10	1	4	14	8	4	—	31	31
	78	—	2	1	3	2	—	—	4	1	3	3	4	3	2	1	3	5	2	—	13	13
	80	—	—	—	1	—	—	—	—	—	—	—	1	—	—	—	—	1	—	—	1	1
Totals ...	...	40	40	40	40	40	40	40	40	40	90	90	90	90	72	72	72	72	72	180	180	360
Relative Humidity per cent.	69	—	1	—	—	—	—	—	1	—	—	1	1	—	2	—	—	—	—	—	2	2
	71	—	3	2	5	2	—	—	2	—	1	3	6	4	—	1	4	9	—	—	14	14
	73	4	8	7	3	7	8	9	6	6	13	18	13	14	6	7	19	10	16	3	55	58
	75	9	9	6	7	10	9	4	11	4	25	16	16	12	11	12	9	15	22	21	48	69
	77	13	9	13	8	8	13	16	11	17	27	24	31	26	19	19	21	25	24	57	51	108
	79	11	7	11	12	9	8	10	7	10	17	25	18	25	19	26	19	11	10	77	8	85
	81	2	2	1	3	3	2	1	2	2	5	3	4	6	9	7	—	2	—	16	2	18
	83	1	1	—	2	1	—	—	—	1	2	—	1	3	6	—	—	—	—	6	—	6
Totals ...	...	40	40	40	40	40	40	40	40	40	90	90	90	90	72	72	72	72	72	180	180	360

The skewness of the breaks distribution is apparent in Tables X and XII, as well as its great scatter. The comparative weakness of the effect of temperature and humidity is plain, and there is no marked departure from linearity. The frequency distributions of Table XIII show the variations associated with the four causes, and Table XIV gives the means. The analysis of the variance is in Table XV, and the mean variance is given in the last column for the breaks only. The mean variance between beams is nearly four times as great as the residual—there is clearly an important variation due to the beams. The differences between the half-day spells are also real, but the mean variances due to periods and days of the week are only a little greater than the residual, and the difference is not statistically significant. There is therefore no evidence that periods or days of the week affect the warp breaks.* The correlation coefficients found from the rows of residuals and totals are given in Table XVI, and show that the only important effect of the elimination has been to reduce the correlation between temperature and relative humidity—suggesting that the relation between these two exists rather in the long-period and systematic effects than in the shorter random fluctuations.

Table XIV

Means of Warp Breaks, Temperatures, and Relative Humidities for Beams, Periods, Days of the Week, and Half-days

Beam	Breaks per 10,000 picks	Temp. °F.	R.H. %		Breaks per 10,000 picks	Temp. °F.	R.H. %
21/1	1·77	67·97	77·13	Period 1	2·21	68·62	76·50
27/3	2·23	71·18	75·75	,, 2	2·09	69·48	75·14
21/2	2·28	69·30	76·20	,, 3	2·18	70·20	76·14
28/4	2·06	72·37	76·75	,, 4	2·03	70·62	77·88
45/3	1·96	70·95	76·30				
22/1	2·17	67·57	76·38	Monday	1·81	67·93	77·65
28/2	2·11	67·95	76·47	Tuesday	2·18	69·29	77·12
46/3	1·96	71·50	75·75	Wednesday	2·16	71·11	75·89
22/2	2·60	68·78	77·03	Thursday	2·22	70·46	75·64
				Friday	2·27	69·86	75·78
Grand Mean	2·13	69·73	76·42	A.M.	2·00	66·59	78·06
				P.M	2·26	72·87	74·77

SUMMARY AND CONCLUSION

It has been shown how, when a quantity varies in response to a number of important causes, the variability associated with these causes may be analysed, and the importance of the effects appreciated. This has been applied to the theory of errors, so that the appropriate variance may be used in estimating the precision of a mean, or of the difference between two means. The analysis leaves a "residual" variance, which represents random deviations which cannot be associated with any cause. It is usually smaller than the total variance, and often experiments can be so arranged that it alone contributes to the sampling errors. As an example of this method of increasing the precision of an experiment a technique for cloth sampling is described. In the problems discussed, the effects of any "treatments" can be regarded as a further cause of variability, and their significance tested by comparing their variance with the residual.

* This analysis could be made still more complete by eliminating the effects of temperature and humidity, but here they are too small to make much difference.

Table XV
Analysis of Variance

Variance due to	Sums of Products: Breaks × Temp.	Sums of Products: Breaks × R.H. %	Sums of Products: Temp. × R.H %	Sums of Squares: Temp.	Sums of Squares: R.H. %	Sums of Squares: Breaks	Degrees of Freedom	Breaks Mean Variance
Beams	− 20·14	+ 1·58	− 125·96	1027·79	77·50	17·746	8	2·22
Periods	− 12·17	− 3·76	+ 23·38	207·70	33·10	1·788	3	0·60
Days of week	+ 48·12	− 38·12	− 281·81	423·74	239·14	9·360	4	2·34
Half-day spells	+147·66	− 77·29	−1859·87	3553·22	973·51	6·136	1	6·14
Residual	− 25·28	−125·69	− 324·82	1391·41	1324·25	229·103	343	0·67
Total	+138·19	−243·28	−2569·08	6603·86	2647·50	264·133	359	—

Table XVI
Correlation Coefficients between Breaks, Temperature, and Relative Humidity

	Total Variations	"Residual" Variations
Raw Coefficients—		
Breaks × Temperature	+·105	−·045
Breaks × R H. %	−·291	−·228
Temperature × R.H. %	−·614	−·239
Partial Coefficients—		
Breaks × Temperature	−·098	−·105
Breaks × R.H. %	−·289	−·246

This test, however, is only exact when the quantity measured is distributed normally. Sometimes, when the distribution is skew, it is possible to make some mathematical transformation (e.g. by taking logarithms) which will reduce it approximately to normality.* When this is not possible, the tests must be accepted with caution, although moderate departures from normality are not likely to invalidate the results. A further difficulty may sometimes arise. If the variability of cloth strengths is analysed into portions between blocks, and a residual within blocks, then the residual variance is an average for the variances within all the blocks. If, however, it is found that the variance within the blocks (taking each one separately) tends to alter with the block mean, then the use and interpretation of the *average* residual given by the analysis becomes somewhat uncertain, and again caution must be observed. Here, too, a mathematical transformation is often possible.

Finally, the importance of the analysis of variability is shown for the interpretation of correlation coefficients, and as an example, the correlation of warp breaks with temperature and humidity is worked out in detail.

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*Owen and Locke used this method in their paper.[6]

THE JOURNAL OF THE
TEXTILE INSTITUTE
TRANSACTIONS

8—FLEECE ANALYSIS FOR BIOLOGICAL AND AGRICULTURAL PURPOSES

THE AVERAGE FINENESS OF A SAMPLE OF WOOL

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CONTENTS

1—GENERAL INTRODUCTION

In order to secure precise knowledge respecting the various characteristics of the fleece, it is necessary to devise a system of fleece analysis. In view of the function of the fleece during its growth on the sheep and its subsequent utilisation, the most obvious characteristics of importance are dimensional, and it is these that are mainly referred to for the present. The system of analysis is required for three main purposes—

(*a*) In order to express in precise terms those characteristics of the fleece of a sheep that affect its utilisation by the manufacturer or its value to the breeder.

Recently the writer (1928) attempted to point out some of the reasons for the neglect of wool improvement, especially by the farmers of this country, and there is little doubt that one factor is ignorance as to what constitutes excellence or the reverse. The measurement of fleece characteristics in precise terms would permit this gap to be

bridged, and would give the farmer the knowledge that would enable him, by selection, to bring the average for a breed nearer to the best. This knowledge would enable the results of chemical, physical, and other research, applied mainly up to the present to problems of utilisation, to be applied also to the problems of production. It can be stated with confidence that the mere existence of this knowledge would make it possible for large improvements in breeding practice to be effected.

The economics of the production of wool as a by-product are very complicated, and the only hope that a scheme in any particular case might effect decided improvement is a recognition of the existence of a number of factors that are interrelated in complex fashion. Only an adequate system of fleece analysis can provide a sure basis for this work.

(*b*) In order to make it possible for breeding experiments to be carried out with precision.

In the past, well-planned breeding experiments have yielded inadequate results because the differences undoubtedly present could not be measured in a satisfactory way. Only when a system of fleece analysis is established will it be possible for the research worker to carry out crossing experiments with any more prospect of securing information than could be secured at present by the practical breeder.

(*c*) In order to measure the differences that may be produced in the fleece by environmental agencies such as climate, nutrition, etc.

Exactly the same argument applies as in the case of breeding experiments.

There are several reasons why a system of fleece analysis for biological and agricultural purposes must be elaborated with this object especially in view. The unit is the complete fleece, whereas it is not the manufacturer's unit. Fleeces are sorted into different portions that may be used for different purposes. Further, wools are often blended at a very early stage in the history of their utilisation. The physicist, too, is mainly concerned with the characteristics of individual fibres, and it is probably true to say that his unit is the single fibre, or even the single fibre at a point. Biological study on the lines mentioned above resolves itself essentially into a study of differences, and, most important of all, a study of the differences between individual sheep. Large numbers must be dealt with, and averages of known variance and significance will be the usual form in which results are stated. The elaboration of methods for biological purposes will, however, often be based on the results of physical research, and it is only physical research that will enable an interpretation to be given, from the point of view of utilisation, of the meaning of the results obtained, especially when these take the form of averages.

Certain characteristics are of great importance to the breeder, but of no interest, or only very indirect interest, to the manufacturer, e.g., the density of the fleece, so that additional measurements have to be included in the scheme.

The requirements for the system of fleece analysis under discussion may be briefly stated.

(1) Methods must be relatively rapid, as large numbers have to be dealt with.

(2) All measurements must be made with controlled accuracy. The degree of accuracy that is necessary will vary according to the material used and the purpose for which the results are required, but the limits of error must be known.

Fineness is one of the most important characteristics of wool, and ultimately it will be necessary to elaborate a system for assessing the fineness of a whole fleece, probably by measuring the fineness at a number of points, few or many. As will be seen, the work involved is very laborious and extensive, and in this paper attention is confined to the first part of the problem, viz., how to estimate the mean fineness of a sample of wool up to a given size. It is clear that if it is possible to estimate the mean fineness of a sample or of the wool growing on a definite area, a simple extension of the work will enable a decision to be made as to the size of samples to be taken from the sheep and the areas to sample, in order to obtain the necessary information as regards that individual. It is hoped to cover this extension of the work in a subsequent paper. It is also hoped that the methods elaborated for the problem dealt with in the present paper will be of use in the solution of the similar problems of the measurement of other characteristics. In many other fields very similar problems are encountered, and in this connection a very important paper by Robinson and Lloyd (1915) on sampling errors in soil surveys is of great interest.

2—OUTLINE OF THE METHOD

The method used for determining the average fineness of a sample is, briefly, to measure the total length of a laboratory sample selected for analysis, and then its total clean dry weight. From this the number of centimetres per milligram is calculated, which gives a measure of fineness. Owing to the constancy of the specific gravity of wool, the quantity measured may be treated as inversely proportional to the average area of cross-section, and therefore inversely proportional to the square of the average diameter.

A preliminary account has been published by the writer (1927), and it was then pointed out that this method was in fact very similar to that used practically, viz., the length of yarn that can be spun from a unit weight of wool. The two measurements correspond to the extent that spinning power depends upon average fineness. The principle of the method is by no means new. The writer would refer to a recent paper by Krauter (1929), which includes a most exhaustive historical account of the various methods that have been used in connection with the measurement of the fineness of wool. It is stated that the principle of the weight-length method was first applied in 1826. In more recent times Barker and King (1926) used the microbalance for determining the fineness of single fibres. Wilkinson (1915) and Krauter (1929) both use a method which involves the simultaneous cutting of a large number of fibres to a known length, followed by a determination of their weight. Both these writers, however, are referring to tops, and as will be explained in a later section, the problem of determining fineness in the case of tops is quite different from that in the case of raw wool.

A critical review of this method and a short comparison with other methods are given in a later section of this paper.

One fundamental principle has governed all the work carried out, viz., that it is necessary to separate off complete pieces or small locks of wool and to deal with every fibre contained in those pieces. The experience of

the writer is that it is a matter of great difficulty to select single fibres from a sample of raw wool in such a way as to make it probable that the conditions of random sampling are being observed. It seems to be inevitable that the longer and coarser fibres catch the eye, and if single fibres are being pulled out, an undue proportion of these are included. A conscious correction of this tendency could only make the sampling yet more unreliable.

The first step is the preparation of the sample. After cleaning and drying, a laboratory sample is taken for analysis. As will be seen later, it is necessary to take a number of sub-samples, using a method of zoning. The fibres are separated out one by one, and it is found that it is unnecessary actually to measure the length of every fibre. All are counted, and the length of a proportion measured, this being effected by measuring every tenth, twentieth, etc., as the case may be. The laboratory sample is re-washed, and its dry weight determined. The calculation is then directly made, and the result stated as centimetres per milligram.

In a later portion of this paper full details of experimental procedure are given, together with the necessary evidence to show the validity of the suggested procedure as it affects the making of the various measurements, and consequently their use as the basis of a statistical argument in the first place and then of a method.

3—THE ATTAINMENT OF CONTROLLED ACCURACY

If a sample of wool is taken and laboratory samples are withdrawn for analysis, each laboratory sample being either a complete piece or else composed of a number of sub-samples, the figures for mean fineness will be distributed with a standard error, S. Further, if not every fibre in the laboratory samples is measured, but only a proportion, it is possible to recognise two independent standard errors which together make up S, and so to analyse the observed variation in fineness. One will be the standard error of the length dispersion, and the other the standard error of the dispersion of fineness of different laboratory samples.

Let S=total percentage standard error.

Let s_1=percentage standard error of mean fibre length.

Let s_2=percentage standard error of fineness dispersion (including other errors of determination).

Then $S=\sqrt{s_1^2+s_2^2}$.

S and s_1 are measured directly, but as s_2 can only be measured directly by the tedious process of analysing a large number of samples in full, it is most conveniently estimated by difference. s_2 will also include the other errors of determination which, as will be seen, are likely to be relatively small.

$$s_2=\sqrt{S^2-s_1^2}.$$

What is required is a knowledge as to the size of the difference between two results that can be treated as significant. A very usual procedure is to treat as significant a difference that exceeds an arbitrary value of twice the standard error (three times the probable error), or three times the standard error (four and a half times the probable error). A better way would appear to be to determine the probability of a given difference being exceeded by chance. For example, for a given set of experiments it might be decided that it would be sufficient if a 5% difference were exceeded by chance not more often than once in 250 times. The use of the probability integral table as given by Galton and Sheppard (1907), Kelley (1923), and Fisher

(1928), enables this calculation to be rapidly made. The method of sampling and the proportion of fibres to be measured for any particular wool can then be decided so as to conform to any desired limits of accuracy.

The special form that this particular problem takes in practice is that of the comparison of two single results and not the divergence of a result from a mean. The magnitude of the errors will have been determined for very similar or almost identical samples, the same procedure having been used, while as regards s_1, the standard error of the length dispersion, a direct estimate of considerable accuracy is possible. Let it be assumed that it is required that a 5% difference will be exceeded by chance not oftener than once in 250 times. From Table I it is seen that the standard error corresponding to this level of accuracy is $\pm 1{\cdot}737$, but as two single results are being compared, and not the divergence from a mean value, the chance of 249 : 1 that a 5% difference is significant corresponds to this standard error divided by $\sqrt{2}$, i.e., $\pm 1{\cdot}228$. It would therefore be necessary to work within this value for S. As, however, duplicate analyses are carried out on each sample, the error is reduced by $\sqrt{2}$, so that in comparing the means of two sets of duplicates, the permissible standard error again becomes $\pm 1{\cdot}737$.

The effect of performing duplicate analyses is to reduce S by $\sqrt{2}$, and not s_2 alone, as might be imagined at first sight; s_1 represents the standard error of the estimates of the total length of a sample based on the measurement of a proportion of its fibres, or, alternatively, it is a measure of the dispersion of fibre length. As the laboratory samples analysed are samples of the same population, the accuracy of this estimate will increase with the number of laboratory samples analysed. If a population of fibres of uniform fineness but variable length were sampled, the number of centimetres per milligram obtained as the result of different analyses would be distributed with a standard error of s_1 (ignoring other errors of determination), s_2 disappearing. Increasing the number of analyses would bring the mean estimate of fineness increasingly nearer the true value.

As in practice the value of the standard error will be an estimate, though an estimate based on the analysis of a large number of very similar or almost identical wools, these values are to be regarded as upper limits, and an endeavour made to work appreciably within them. Another reason for caution is that the values for the standard error are based on the assumption of normality, and although, as will be shown, there is reason to believe that the dispersions described in this paper do not diverge seriously from the normal distribution, even a small divergence in the case of the higher limits of accuracy may produce an appreciable effect.

The values of the standard error for the difference of single results in the table are useful, because they can be used for checking purposes. In the example already given, it is seen that working to these limits the chance that the duplicate results from the same sample will differ from each other by more than 5% is about 1 in 25. If, therefore, working to the limits in the example quoted, the duplicate results were to differ by this amount more often than once in 25 times, this would be an indication that the permissible standard error was being exceeded. This check may be amplified by calculating the chances that differences of various amounts will be exceeded, thus giving a check as results accumulate that can be applied almost at a glance.

Table I

Deviation Exceeded once in	Corresponding Percentage Standard Error: For 5% Difference — Deviation from Mean *or* Difference of Means of Duplicates	For 5% Difference — Difference of Single Results	For 10% Difference — Deviation from Mean *or* Difference of Means of Duplicates	For 10% Difference — Difference of Single Results	For 20% Difference — Deviation from Mean *or* Difference of Means of Duplicates	For 20% Difference — Difference of Single Results
25 times	2·435	1·722	4·869	3·443	9·739	6·886
50 ,,	2·149	1·520	4·299	3·040	8·597	6·079
100 ,,	1·941	1·373	3·882	2·745	7·765	5·490
250 ,,	1·737	1·228	3·474	2·457	6·949	4·914
500 ,,	1·618	1·414	3·236	2·288	6·472	4·577
1,000 ,,	1·520	1·075	3·039	2·149	6·078	4·298

It is to be specially noted that as the unit of measurement, viz., centimetres per milligram, is inversely proportional to cross-sectional area, and therefore to the square of the diameter, accuracies of 5%, 10%, and 20%, correspond to accuracies of 2½%, 5%, and 10% in the case of the ordinary method of stating fineness in terms of diameter.

4—SHORT FIBRES

Before dealing with the application of statistical method to results and the arguments underlying the whole procedure, one point must be made clear. It will be found that almost every wool sample contains a proportion of fibres which, compared with the bulk of the sample, are relatively very short. In many cases the occurrence of these fibres is to be ascribed to breakage, as it is almost impossible to separate locks of wool without breaking a certain number of fibres. With a little practice, however, the amount of such breakage in the handling of the wool can be reduced to a minimum.

It is found that if all the very short and broken fibres, including perhaps a few extremely short pieces, are measured together with the main sample, the dispersion of fibre length becomes a very wide one, and in addition shows very considerable skewness. As the object to be attained is a measure of the total length of the sample, there is no objection in principle to a separation being effected, and the very short and broken fibres being treated apart from the main sample. For example, in the case of a wool with, say, a mean fibre length of 20 centimetres, those fibres that are shorter than 9 or 10 centimetres, as judged by eye, may be separated from the rest as they turn up during the course of analysis. In the case of wools of different lengths, different arbitrary limits will be fixed. For example, in the case of a Merino wool with a mean fibre length of 11 centimetres, fibres shorter than 5 or 6 centimetres may be put into the special group. It has been found during the analysis of large numbers of samples of various kinds of wool that, with reasonable arbitrary limits of the kind described, the contribution of the short and broken fibres to the total length of the sample is a very small one. The largest contribution to the total length of the sample obtained by the writer was 5·8%, and this was quite an exceptional figure. The contribution may range from 0·3% upwards, and will not often exceed 3 or 4%.

It is clear that the estimate of the total length of the short and broken fraction need not be of the same accuracy as the estimate required for the main fraction. Ordinarily an accuracy of only 1/30th of the accuracy for the main fraction will be required. The length dispersion of the short fibres is by no means normal, but nevertheless if the same proportion is measured as in the case of the main fraction, the necessary accuracy is amply attained. In practice either the same proportion is measured, or if, as frequently happens, the number of short and broken fibres in the sample is relatively small, a larger proportion is measured, because in certain cases a measurement of the same proportion as in the case of the main fraction would mean that only two or three of the short fibres were actually measured.

In the immediately following statistical argument of this paper, the length dispersion treated is the length dispersion of the main sample. If the whole problem of length measurement can be solved for the main fraction of the sample, the contribution of all the short fibres can readily be estimated with sufficient accuracy, and is so small that, as will be seen, the determination of the number and proportion of fibres to measure, etc., will not be appreciably affected.

5—THE NORMALITY OF THE DISPERSIONS

The methods and tests used in connection with this work would apply to distributions that diverged considerably from the normal, nevertheless it may be of interest to give some data on this point, especially as regards the dispersion of fibre length. Table II gives some typical results.

Table II

	No. of Fibres	Mean Length	Standard Deviation	γ_1	γ_2	Percentage Observations outside $M \pm 1.015\sigma$ Figure for Normal Distribution $=31$	Percentage Observations outside $M \pm 2\sigma$ Figure for Normal Distribution $=4.5$
Border Leicester, complete lock. All fibres measured ...	3,328	20·259	$\pm 3{\cdot}329$	$-0{\cdot}468$ $\pm 0{\cdot}042$	$+0{\cdot}288$ $\pm 0{\cdot}086$	26	4·5
Same sample, weight 80 g., 12 zoned laboratory samples, average number of zones 40; 1 in 10, or 1 in 20 fibres measured	1,515	19·825	$\pm 3{\cdot}188$	$-0{\cdot}486$ $\pm 0{\cdot}063$	$-0{\cdot}026$ $\pm 0{\cdot}126$	30	5·1
Merino, complete lock. All fibres measured. ...	226	11·814	$\pm 1{\cdot}077$	$-0{\cdot}116$ $\pm 0{\cdot}163$	$-0{\cdot}020$ $\pm 0{\cdot}326$	29	5·1

Two tests are applied. In the first place the method given by Fisher (1928), page 52, is used, the values for γ_1 and γ_2, calculated from the third and fourth moments, having been worked out.

γ_1 ($=\pm\sqrt{\beta_1}$) is a measure of skewness, and is zero for a normal dispersion. There is always some skewness in the length dispersion due to an

excess of fibres falling into the short frequency classes. It is probably to be ascribed largely to fibre breakage.

γ_2 $(=\beta_2-3)$ is a measure of a symmetrical type of departure from the normal distribution, by which the apex and tails of the curve are increased at the expense of the intermediate portion, or if it is negative the departure from normality takes the opposite form. In the present case γ_2 is sometimes positive and sometimes negative, usually the former. The values are not large, however, and do not always exceed their standard errors.

It is doubtful if in this particular case this method provides exactly the information required, viz., to what extent the important part of the distribution is reasonably normal. Accordingly the number of observations falling outside two different ranges have been calculated, and are compared with the theoretical figure for the normal distribution. It will be seen that γ_1 and γ_2 do indicate some departure from the normal distribution, but that the important part of the distribution is much more normal than would be indicated by these parameters, as is shown by the number of observations falling inside and outside the selected arbitrary portions of the range.

As a system of zoning has been adopted in the selection of the laboratory sample, it was thought that it would possibly be useful to test whether the measurement of fibres drawn from relatively large samples would show a greater departure from normality than would the measurements of fibres forming a complete lock of wool. As will be seen from the table, this does not appear to be the case. It may be fairly concluded, therefore, that the length dispersion does not depart appreciably from normality in the case of samples up to the limits of size dealt with in this paper, and the necessary formulæ may be applied with confidence.

With regard to the other dispersion that is used in this paper, viz., that of the values for fineness of a sample, normality cannot be directly tested as such large numbers are required. The assumption of normality is reasonable, however, because such values for fineness are based upon a number of estimates of the fineness of the same complete sample. The purpose of zoning is to secure some degree of mixing, so that successive laboratory samples drawn for analysis are, as far as possible, similarly constituted. It is known that measurements obtained in this way tend to be normally distributed.

6—THE CALCULATION OF THE NUMBER OR PROPORTION OF FIBRES TO BE MEASURED. TABBING VERSUS RANDOM SAMPLING

This calculation will ordinarily be made as follows. The mean fibre length and standard deviation being known, the percentage standard deviation is calculated. In relation to all the other factors involved, a maximum value is then fixed for the standard error of length sampling. Let this value be $\pm s_1$. Then

$$s_1 = \frac{\text{Percentage standard deviation}}{\sqrt{n}}$$

$$\textit{or } n = \text{Number of fibres to be measured.}$$

$$= \left(\frac{\text{Percentage standard deviation}}{s_1}\right)^2$$

This formula applies when the number of measurements is small in comparison with the total population. The full formula is—

$$\frac{\sigma}{\sqrt{n}} \times \sqrt{\frac{N-n}{N-1}}$$

$$or\ n = \left(\frac{S.D.\%}{s_1} \times \sqrt{\frac{N-n}{N-1}}\right)^2$$

where N is the total population and n the number of observations. It will be seen that the divergence is considerable if the observations form a large proportion of the population. Within the limits of any laboratory sample likely to be encountered, say 400–4,000 fibres, the expression $\sqrt{\frac{N-n}{N-1}}$ is sufficiently constant for each proportion up to the number of places of decimals given throughout this paper. Accordingly Table XIV has been constructed for proportions of 1 in 4 up to 1 in 20 and all that is necessary is that the standard error obtained in the ordinary way by dividing σ by $\sqrt{n}$ should be multiplied by the appropriate correction factor from the table.

It will be noted that as long as the sample whose average fineness it is required to determine can be regarded as a population of fibres of normal length dispersion, the number to be measured is independent of the size of laboratory sample taken, apart from the correction when the proportion measured becomes high. The number of fibres to be measured being known, the size of the laboratory sample is determined by other considerations, e.g., a reasonable total quantity to weigh, and a quantity such that it is possible to include a reasonable number of zones. The average weight per fibre being approximately known (or rapidly estimated), the proportion of fibres to be measured in the laboratory sample is determined.

For the purposes of the paper, samples have been used up to a clean air weight of 130 g., and up to this limit at least it is permissible to treat the population of fibre lengths as normally distributed and, therefore, to apply the formula.

Another method has been employed for arriving at the same result, and a comparison of the results obtained by both on the same sample is of value as a check. If all the fibres contained in a laboratory sample are measured, they can be numbered in order 1 to 16, then starting with 1 up to 16 again, and so on until the sample is finished. If now all the 1's, all the 2's, etc., are summed up separately, sixteen estimates of the total length of the sample, or of the mean fibre length, are obtained, each of these results being comparable with the estimate as obtained by the method already described. A percentage standard error can then be calculated and compared with the standard error obtained by dividing the percentage standard deviation for length by the root of the number of observations, and multiplying by $\sqrt{\frac{N-n}{N-1}}$. The following table is taken from the results of the analyses of laboratory samples obtained by dividing a single piece of wool by a method of successive division. The figures are based on too few results for a comparison to be made between the figures for each laboratory sample separately, but the means of the twelve results in each case may be safely used.

It will be seen in the table that the total number of fibres in each sample is a multiple of sixteen. This was necessary in order to secure a comparison, so the excess less than sixteen was in each case omitted from the calculation.

Table III
Border Leicester. Shoulder. Complete Lock.

Sample	No. of Fibres	$s_1 = \frac{S.D\ \%}{\sqrt{n}} \times \sqrt{\frac{N-n}{N-1}}$ ±	s_1 Directly Determined every 16th Fibre ±	s_1 Directly Determined every 8th Fibre ±	s_1 Directly Determined every 4th Fibre ±
Aa 1 (1)	336	3·55	3·07	2·65	1·74
(2)	240	4·06	4·47	3·00	0·68
2 (1)	336	3·22	3·61	2·45	1·77
(2)	160	4·29	4·87	4·59	1·58
(3)	304	3·31	3·92	3·32	1·83
b 1 (1)	320	3·37	3·36	2·83	1·74
(2)	304	3·56	3·47	2·86	1·00
2 (1)	240	4·22	3·96	2·01	1·11
(2)	256	4·12	3·96	2·17	1·58
c 1 (1)	320	2·94	3·48	2·19	1·63
2 (1)	320	3·76	2·96	2·72	1·00
(2)	192	4·43	3·62	3·26	2·39
	3,328	3·74	3·73	2·84	1·50
			s_1 from % $S.D.$ =3·74	s_1 from % $S.D.$ =2·55	s_1 from % $S.D.$ =1·67

The correspondence between the standard errors as calculated by the two methods is remarkably close.

Another most important consideration emerges from a study of these figures. The fibres to be actually measured are selected not by random sampling but by a process of tabbing, for reasons already explained. It is of great importance to know whether in regard to this particular method for determining wool fineness this process gives results comparable with random sampling. The correspondence of the standard errors given shows that this is the case. It may be concluded from this that in the case of the length sampling of wool, the process of tabbing gives results that correspond closely with those that would be obtained by random sampling.

As a check on the results given in Table III a further set of results was worked out. The figures for fibre length are not strictly comparable with those given in the rest of this paper, because they were obtained at an early stage when a method was being used by which all fibres were included in a single main fraction except extremely short pieces, which were ignored. The contribution of such very short pieces being small, even if they possessed a fineness very different from that of the main sample, their omission could not appreciably affect the result. The figures are given in Table IV.

Table IV
Welsh Mountain. Shoulder. Complete Lock. 1,920 Fibres.

	$s_1 = \frac{S.D.\%}{\sqrt{n}} \times \sqrt{\frac{N-n}{N-1}}$ ±	s_1 Determined Directly ±
Every 32nd fibre	3·59	3·50
„ 16th „	2·49	2·07
„ 8th „	1·70	1·44
„ 4th „	1·12	0·82

Again all the fibres formed a complete lock, which was divided into three pieces and the results worked out separately. The mean of the three figures is given in each case. Speaking generally, these results confirm those given in Table III.

In practice the value of s_1 is based upon the percentage standard deviation obtained by the measurement not of all the fibres in the laboratory sample but of a proportion only. The value for s_1 obtained in this way is, however, an estimate of considerable accuracy. For example, in Table X the analysis of a Shropshire sample is given. 140 fibres were actually measured. The mean length in centimetres was $14{\cdot}54 \pm 2{\cdot}53$. The standard error of the standard deviation is $\pm 0{\cdot}141$, so that the chance that the true value of the standard deviation lies between $\pm 2{\cdot}81$ and $\pm 2{\cdot}25$ is 21:1. Using these figures the expectation is that the value for s_1 lies between $\pm 1{\cdot}53$ and $\pm 1{\cdot}20$, with this degree of probability. The figure used was 1·37. Taking another result from the same table, that of the sample in the case of which the smallest number of fibres was measured, the result is as follows. 48 fibres were actually measured, the mean length in centimetres being $9{\cdot}36 \pm 0{\cdot}76$. The standard error of the standard deviation is $\pm 0{\cdot}0776$, so that the expectation is that the true value for s_1 lies between $\pm 1{\cdot}40$ and $\pm 0{\cdot}94$, the chances being 21:1. As the permissible value for s_1 is to some extent an arbitrary estimate, and as it is always regarded as an upper limit, it will be seen that a reasonable accuracy is attained even if comparatively few fibres are measured.

The actual method of selection of the laboratory samples involves a system of zoning, and it is necessary to know whether the multiplication of zones complicates the estimation of the standard deviation of fibre length. Results show that this is not the case. With samples up to the limit of size described in this paper, the standard deviation of fibre length in the case of laboratory samples made up of a number of pieces does not differ appreciably from the standard deviation determined by the measurement of the fibres contained in a single piece of wool. Also, as has already been mentioned, the normality of the length dispersion is not appreciably affected.

7—THE FINENESS DISPERSION. ZONING

Ultimately it will be necessary to decide upon a procedure for sampling an entire fleece, but in the present paper attention is confined to the first problem of obtaining a figure for the mean fineness of a sample. It is very desirable to form some estimate in the first place of the variation of the mean fineness of small pieces of wool from point to point over small areas, and then over larger areas. Table V gives the results of the analysis of a single piece of wool (Border Leicester, shoulder sample) of less than a gram in weight. This small lock was divided into twelve pieces by successive division and the length of all the fibres was measured in each case, so that the error of length sampling was eliminated and a direct measure of s_2 was possible. S in this case is equal to s_2, including also any other errors of determination.

It will be seen that even in such a very small piece of wool the variation from point to point is considerable, and is in fact already approaching the order of magnitude permissible if 5% differences are to be treated as reasonably significant. The difference between the highest and lowest values is one of 4·5% (with no error of length sampling).

Table V

Border Leicester. Shoulder—Complete Lock. Approximate Clean Air Weight 0·9 g. Divided by Successive Division. All Fibres Measured.

Sample	No. of Fibres	Dry Weight in mgs.	Fineness in cms. per mg.
Aa 1 (1)	347	83·2	87·0
(2)	254	60·8	85·6
2 (1)	338	80·2	85·4
(2)	176	44·5	83·3
(3)	328	76·0	86·8
b 1 (1)	330	81·4	84·8
(2)	314	75·3	86·8
2 (1)	254	62·0	84·0
(2)	269	66·7	83·9
c 1 (1)	331	76·4	87·1
2 (1)	324	77·4	84·6
(2)	178	46·7	84·4

Mean Fineness = 85·3
Standard Deviation = $\pm 1{\cdot}35$
Standard Deviation % $= s_2 = \pm 1{\cdot}58$

The next step is to consider the variability of fineness from point to point in a larger sample. A sample of wool weighing in air when washed about 5 g. was selected from the same Border Leicester shoulder sample. This 5 g. sample, known as C2, was clipped off from a square on the skin with a side of approximately 4 cm. In this case not all the fibres were measured, but a proportion of one in four. Using the figure calculated from the measurement in full of over 3,000 fibres from the same big sample, a comparatively reliable estimate of s_1 is possible. In any case s_1 is very small in comparison with s_2.

The results of eight analyses are shown in Table VI.

Table VI

Border Leicester. Shoulder Sample. C2
Approximate Clean Air Weight 5 g. Approximate Area of Skin on which Grown 16 sq. cms.

Single Random Laboratory Samples			Zoned Laboratory Samples				
No. of Fibres actually measured	Proportion measured	Fineness cms. per mg.	No. of Zones	No. of Fibres actually measured	Proportion measured	$s_1 = \frac{S.D.\%}{\sqrt{n}} \times \sqrt{\frac{N-n}{N-1}}$ $\pm$	Fineness cms. per mg.
61	1 in 4	80·4	16	125	1 in 10	1·40	77·9
57	,,	78·0	16	125	1 ,, 10	1·19	81·2
62	,,	84·8	31	121	1 ,, 20	1·48	79·2
79	,,	84·4	10	123	1 ,, 10	1·48	78·0
65	,,	75·2	22	118	1 ,, 20	1·48	77·1
57	,,	76·2	12	115	1 ,, 10	1·32	80·2
83	,,	76·3					
71	,,	77·0					

Mean Fineness = 79·0
Standard Deviation = $\pm 3{\cdot}77$
Standard Deviation % = $\pm 4{\cdot}77$
Estimate of s_1 = $\pm 1{\cdot}5$
$s_2 = \sqrt{(4{\cdot}77)^2 - (1{\cdot}5)^2} = \pm 4{\cdot}53$

Mean Fineness = 78·9
Standard Deviation = $\pm 1{\cdot}56$
Standard Deviation % = $\pm 1{\cdot}98$
s_1 = $\pm 1{\cdot}39$
$s_2 = \sqrt{(1{\cdot}98)^2 - (1{\cdot}39)^2} = \pm 1{\cdot}41$

The differences are extraordinarily large, the value for the percentage standard error of the fineness dispersion being $\pm 4{\cdot}53$. The difference between the highest and the lowest values is one of 12·2%.

Another square of similar size from the same big sample gave a very similar though slightly less variability, but a third square, D3, showed remarkable evenness.

The results for square D3 are given in Table VII.

Table VII

Border Leicester. Shoulder Sample D3. Approximate Weight and Area same as C2 : D3 and C2 taken from same Big Sample. Diagonally Adjacent Squares.

Single Random Laboratory Samples			Single Random Laboratory Samples		
No. of Fibres actually measured	Proportion measured	Fineness cms. per mg.	No. of Fibres actually measured	Proportion measured	Fineness cms. per mg.
50	1 in 4	91·6	85	1 in 4	90·0
52	1 ,, 4	91·8	68	1 ,, 4	90·3
58	1 ,, 4	87·7	293	all	90·9
73	1 ,, 4	88·3			

Mean Fineness	= 90·1
Standard Deviation	= $\pm 1{\cdot}57$
Standard Deviation %	= $\pm 1{\cdot}75$
Estimate of s_1	= $\pm 1{\cdot}5$
$s_2 = \sqrt{(1{\cdot}75)^2 - (1{\cdot}5)^2}$	= $\pm 0{\cdot}90$

Duplicate zoned samples, 14 and 10 zones respectively, gave 89·8 cms. per mg. and 88·9 cms. per mg. Mean 89·4 cms. per mg.

The standard error of the fineness dispersion is in this case only $\pm 0{\cdot}90$, and the difference between extreme values is one of only 4·6%. Samples C2 and D3 were taken from the same larger sample and these squares were actually diagonally adjacent. The degree of variability, therefore, even in a comparatively small piece of wool, is as erratic as the values for the distribution of fineness.

The whole big sample from which the smaller samples were taken was now investigated. This was a sample of approximately 80 g. clean air weight, taken from the shoulder of a Border Leicester sheep and growing on a square of skin with a side of approximately 16 cm. The results are given in Table VIII.

The standard error of the fineness dispersion is $\pm 6{\cdot}96$. The same estimate for s_1, viz., $\pm 1{\cdot}5$, is used and is quite insignificant in comparison with s_2. The difference between extreme values is now 24·8%.

The utter unreliability of any estimate of the mean fineness of a sample based on the analysis of a single laboratory sample drawn from it, makes it imperative that a different method of sampling must be elaborated. In chemical analysis, the complete sample is mixed thoroughly before laboratory samples are withdrawn, but in the present case such a procedure is out of the question. It is difficult to mix wool, and in the process the fibres would become inextricably entangled. A method of zoning is, however, possible. If the big sample whose mean fineness is to be determined is carefully divided into a number of approximately equal pieces, a single sub-sample may be drawn from each of these pieces. These sub-samples may be directly

separated off from the complete main sample, if for any reason it is desired not to break this up.

Table VIII

Border Leicester. Entire Shoulder Sample. Approximate Clean Air Weight 80 g. Taken from Square with Side of 16 cms.

Single Random Laboratory Samples			Zoned Laboratory Samples					
No. of Fibres actually measured	Proportion measured	Fineness cms. per mg.	No. of Zones	No. of Fibres actually measured	Proportion measured	$s_1 = \frac{S.D.\%}{\sqrt{n}} \times \sqrt{\frac{N-n}{N-1}}$ $\pm$	Fineness cms. per mg.
65	1 in 4	84·6	32	130	1 in 20	1·46	84·0
62	,,	73·2	48	126	1 ,, 20	1·59	82·9
74	,,	74·9	48	125	1 ,, 20	1·38	82·7
60	,,	74·3	64	125	1 ,, 20	1·22	84·3
52	,,	91·8	48	126	1 ,, 20	1·41	85·1
73	,,	88·3	32	122	1 ,, 10	1·36	83·1
75	,,	89·8	48	124	1 ,, 20	1·36	85·1
51	,,	85·9	32	118	1 ,, 10	1·40	84·7
51	,,	79·8	32	129	1 ,, 10	1·28	86·5
54	,,	81·8	32	129	1 ,, 10	1·40	84·8
79	,,	84·4	32	127	1 ,, 10	1·31	83·0
57	,,	78·0	32	123	1 ,, 10	1·26	82·5
70	,,	82·2					
74	,,	89·9					
51	,,	74·6					
55	,,	80·6					
67	,,	84·4					
61	,,	79·3					
75	,,	90·5					
76	,,	87·1					
69	,,	89·7					
81	,,	87·1					
89	,,	85·4					
59	,,	90·2					
69	,,	87·3					
82	,,	92·0					
77	,,	91·9					
62	,,	81·8					
66	,,	88·0					
67	,,	89·1					
73	,,	94·3					
76	,,	93·2					

Zoned Laboratory Samples:

Mean Fineness = 84·1

Standard Deviation = $\pm 1{\cdot}24$

Standard Deviation % = $\pm 1{\cdot}48$

$s_1 = \pm 1{\cdot}37$

$s_2 = \sqrt{(1{\cdot}48)^2 - (1{\cdot}37)^2} = \pm 0{\cdot}56$

Single Random Laboratory Samples:

Mean Fineness = 85·2

Standard Deviation = $\pm 5{\cdot}94$

Standard Deviation % = $\pm 6{\cdot}98$

Estimate of s_1 = $\pm 1{\cdot}5$

$s_2 = \sqrt{(6{\cdot}98)^2 - (1{\cdot}5)^2} = \pm 6{\cdot}96$

The effect of zoning in reducing the variability of the estimate of sample fineness is shown in Tables VI, VII, and VIII. In the case of C2, s_2 is reduced from $\pm 4{\cdot}53$ to $\pm 1{\cdot}41$, and the difference between the highest and lowest values from 12·2% to 5·2% (including the error of length sampling). In the case of the whole sample (Table VIII) s_2 is reduced from $\pm 6{\cdot}96$ to $\pm 0{\cdot}56$, and the difference between the highest and lowest values from 24·8% to 4·8% (including the error of length sampling). A proper system of zoning is, therefore, the key to obtaining a reasonably accurate value for the mean

fineness of a sample. In order to separate out sub-samples of reasonable and convenient size, the total size of laboratory samples in the case of medium and coarse wools is increased, so that in most cases the proportion of fibres to be measured becomes less than one in eight, and the number to be measured independent of the size of the laboratory sample. This difference is seen in the tables. The calculation of the number to be measured is readily made from the length dispersion. An estimate of considerable accuracy is possible with the first two or three samples analysed in the ordinary way, and can be checked up as analyses accumulate.

As far as the big Border Leicester sample is concerned, the table shows that 32 zones at most are sufficient. An increase in the number of zones beyond this does not lead to any appreciable increase in accuracy. Further determinations on other wools and on yet larger samples confirm the view that in all probability this number is sufficient for samples up to the size dealt with in this paper, provided of course that they are single samples and not mixtures of wools of very different characteristics. It is very difficult to lay down precise rules as to the number of zones in different cases, because of the infinite variability in the characteristics of different kinds of wool, but it would seem probable that with smaller samples of, say, 20 g. or less, the number of zones may be reduced perhaps to as few as 12. However, a reduction in the number of zones can only appreciably reduce the time taken for analysis if the full number, say 32, involves the counting, as distinct from measuring, of a large number of fibres. A decrease in the proportion measured to less than 1 in 20 does undoubtedly add appreciably to the time taken, but a decrease in the number of zones will not often make much difference in this respect, as it will be mainly in the finest wools that the proportion to be measured is very small, and in the finest wools the limiting factor is usually the total size of the laboratory sample.

It should be made clear that the variability of this Border Leicester sample is in no way abnormal. In fact the sample was originally taken as likely to represent a relatively uniform sample of a coarse wool! The large differences in fineness shown in the tables could readily be distinguished by eye, and ordinary visual examination of other samples of various kinds of wool revealed differences larger in some cases than those shown by the Border Leicester sample.

It might be pointed out in parenthesis that similar variability in fibre length is also found, but considered on a percentage basis is much less than the variability of fineness. A difference in mean fineness of 24·8% corresponded to a difference of 8·9% in mean fibre length.

It is doubtless true that the variability of very fine wools is not as great as that of coarse wools, but nevertheless a considerable variability can be found, certainly of an order that makes it necessary for the zoning procedure to be adopted if the mean fineness of a sample is required. A Merino skin was used, the wool growing on which was the most uniform as regards fibre length, and also probably as regards fineness, of any wool yet examined by the writer. The wool of the shoulder regions would probably be of about 64's quality, but none of the wools finer than this examined showed so great an evenness. The results of the analysis of six complete laboratory samples, taken from a sample of only 3½ g. from the shoulder region of this skin, are given in Table IX. The standard error of the fineness dispersion was $\pm 2{\cdot}15$ and the percentage difference between the highest and lowest values 6·8.

Table IX

Merino. Shoulder Sample. Clean Air Weight 3·5 g. Taken from Square of 10 sq. cms (on Dried Skin)

No. of Fibres actually measured	Proportion measured	$s_1 = \frac{S.D.\%}{\sqrt{n}} \times \sqrt{\frac{N-n}{N-1}}$ $\pm$	Fineness cms. per mg.
40	1 in 20	1·50	219·2
44	1 ,, 20	1·27	224·6
37	1 ,, 20	1·06	224·2
48	1 ,, 20	1·01	217·8
226	all	nil	227·1
35	1 in 20	1·52	
124	all	nil	233·0
40	1 in 20	1·10	

Mean Fineness	= 224·3
Standard Deviation	= $\pm$5·51
Standard Deviation %	= $\pm$2·46
Estimate of s_1	= $\pm$1·2
$s_2 = \sqrt{(2{\cdot}46)^2 - (1{\cdot}2)^2}$	= $\pm$2·15

Duplicate zoned samples, 14 and 18 zones respectively, gave 227·1 cms. per mg. and 226.6 cms. per mg. Mean 226·9 cms. per mg.

A square of ten times this size from the same region and including the small square, showed about the same variability. The standard error of the fineness dispersion was $\pm$2·38 and the extreme difference 7·5%.

The adequacy of the zoning procedure was further tested by duplicate analyses on a number of different wools, some of them being selected as likely to show very great variation. The results are given in the next section.

The conclusions are clear. In the first place the variability of the mean fineness of small samples of wool over even relatively very small areas may be surprisingly large. In the second place the method of zoning permits an estimate of the mean fineness of a sample to be made with sufficient accuracy. It is also clear that to base conclusions on measurements of the fineness of small samples, say 3–5 g., as unfortunately has only too often been the case, is a procedure that must lead to results of an entirely misleading character. The true mean fineness of a small sample of, say, 5 g. or so of wool, may differ very considerably from that of another small sample taken from an adjacent area of skin. How to sample a sheep is, however, a subject the consideration of which is deferred to a later paper.

8—RESULTS IN DETAIL FOR VARIOUS TYPES OF WOOL

The table shows the relevant data for determining size of laboratory sample, number and proportion of fibres to count, etc., for various types of wool. All the results have been obtained on the basis that a 5% difference should be significant with a chance of 249:1, the mean of duplicate analyses being taken in each case. The values for the pairs of duplicate results may differ from each other by more than 5% not more often than once in about twenty-five times. In the case of the fourteen wools for which duplicate results are given this difference is not exceeded at all, the mean difference being 2·1%; and the largest difference 4·5%, so that the work has been carried out up to this point within the permissible limits. As results accumulate this consideration forms an increasingly valuable check on the details of the procedure.

Table X

Analyses of Various Wools to Illustrate Details of Procedure

Description of Sample	Approximate Clean Air Weight of Sample g.	Approximate Area of Skin from which taken sq. cms.	Dry Weight of Laboratory Sample mg.	No. of Zones	No. of Fibres actually measured	Proportion of Fibres measured	Average Length	Standard Deviation ±	$^{*}s_1 = \frac{S.D.\%}{\sqrt{n}}$ ±	Fineness in cms. per mg.	
Australian Merino 74's ...	2·7	—	51·1	18	80	1 in 20	9·47	0·70	0·80	299·4	
			59·7	18	48	1 ,, 40	9·36	0·76	1·14	310·1	304·7
Australian Merino 70's ...	5·3	—	59·8	16	70	1 ,, 20	10·79	1·33	1·43	265·8	
			61·2	16	71	1 ,, 20	11·03	1·20	1·25	268·6	267·2
Australian Merino 66's ...	6·6	—	71·5	16	75	1 ,, 20	12·52	1·51	1·35	272·0	
			62·6	16	71	1 ,, 18	12·74	1·30	1·16	269·1	270·6
Australian Merino 64's ...	6·4	—	87·4	24	77	1 ,, 20	12·38	1·60	1·42	225·3	
			73·5	16	84	1 ,, 15	12·52	1·59	1·32	223·4	224·4
Australian Merino 60's ...	6·7	—	94·3	16	80	1 ,, 20	12·10	1·38	1·24	210·2	
			65·3	16	94	1 ,, 12	12·39	1·56	1·24	219·2	214·7
Australian Merino 58–60's ...	5·9	—	72·1	16	57	1 ,, 20	12·91	1·41	1·39	209·5	
			71·9	16	110	1 ,, 20	12·73	1·39	1·00	200·2	204·9
Australian Merino, shoulder ...	35	100 (dried skin)	146·2	32	72	1 ,, 40	11·65	0·92	0·92	233·4	
			157·5	48	66	1 ,, 45	11·67	1·20	1·25	225·5	229·5
Australian Crossbred ... ... (fine anomalous sample)	11·5	—	55·9	16	95	1 ,, 10	13·94	1·92	1·34	241·5	
			63·3	16	103	1 ,, 10	14·00	2·07	1·40	235·1	238·3
Australian Crossbred 50's ...	103	—	202·2	32	176	1 ,, 10	15·36	2·92	1·36	137·1	
			140·5	32	206	1 ,, 6	15·31	2·83	1·18	137·9	137·5
Lincoln, britch, partly grown...	27	100 (dried skin)	469·6	32	143	1 ,, 15	13·12	2·18	1·33	64·1	
			413·4	32	158	1 ,, 12	13·16	2·22	1·28	64·4	64·2
Border Leicester, shoulder ... (Mean of results see Table VIII)	80	256	{296·3, 603·4}	32–64	125	{1 ,, 10; 1 ,, 20}	19·83	3·17	1·42		84·1
Suffolk, britch, partly grown...	3·9	—	197·5	16	86	1 ,, 20	8·48	1·04	1·28	77·6	
			102·6	16	87	1 ,, 10	8·68	1·11	1·29	78·3	78·0
Shropshire 50's	130	—	204·5	32	122	1 ,, 10	14·80	2·54	1·47	93·5	
			192·0	32	140	1 ,, 8	14·54	2·53	1·37	91·6	92·6
Cheviot, shoulder	13	64	115·9	32	146	1 ,, 5	18·11	2·96	1·21	117·9	
			117·3	32	143	1 ,, 5	17·84	2·85	1·20	113·1	115·5
Welsh Mountain, side ...	3·0	—	91·2	32	120	1 ,, 5	14·07	2·18	1·26	97·0	
			103·8	16	136	1 ,, 5	14·24	2·08	1·14	96·8	96·9

* Corrected for size of population. See Table XIV.

In the wools shown in the table the number of fibres measured ranges from 48 to 206 (though in this last case an unnecessarily high accuracy has been attained). If it were sufficient that a 10% difference, i.e., a 5% difference in mean diameter, should be significant with a chance of 249:1, only one quarter of this number of fibres need be measured, and the figures in the table would range from 12 to 51. As for many purposes this accuracy would be sufficient, it will be realised how speedy a process this method of measurement of fineness can be. Probably in the case of almost any Merino wool not more than 25 fibres would have to be actually measured to attain a 10% accuracy, corresponding to a 5% accuracy of results as stated in terms of mean fibre diameter.

9—THE RECOMMENDED PROCEDURE IN DETAIL

(i) Selecting the Original Sample

As attention is confined, as far as the present paper is concerned, to obtaining a figure for the mean fineness of a sample, little need be said here regarding the selection of such a main sample. It has been assumed that usually the sample will be a complete piece of wool, either clipped off an area of skin or separated from a fleece. There is no reason why the method should not be extended to cover the case of a sample which is composed of similar locks of wool taken from different parts of a fleece, or even from different fleeces, but in such a case great care must be taken to make certain that the procedure adopted is actually giving results that will fall within the prescribed limits of error. A comparison of duplicate analyses of the same sample, or preferably a comparison of the results of several analyses, enables this check to be applied.

The largest sample dealt with during the course of the work described in this paper was 130 g. (clean air weight). There is no reason to suppose that considerably larger samples could not be dealt with in the same way. This will be discovered in practice for any type of wool as observations accumulate. It is hoped to deal further with the problem when the work is extended to cover a procedure for the analysis of complete fleeces for fineness.

(ii) Washing the Sample

On the general question of the preparation of wool before analysis Barritt and King (1926) may be consulted.

A standardised procedure has been adopted in connection with the work described in the present paper. It is convenient if the complete sample can be washed as the first step in the whole process. The wool is treated with three changes of benzene warmed to about 40° C. After each change the wool is carefully squeezed as dry as possible, care being taken during all the cleaning processes to disturb the fibres as little as possible. After the final change of benzene the wool is allowed to dry in the air and is then treated with three changes of distilled water. If desired a very small trace of saponin can be added to the second change. After squeezing, the surplus water is roughly removed between filter papers, and the sample allowed to dry in the air overnight.

Cold ether may be substituted for the benzene and gives just the same result, but the use of benzene is preferable on grounds of economy and greater safety. It is also a better solvent for wool grease. Another important point is the behaviour of the fibre towards the solvents, as has been shown by Hirst (1922) and King (1926). Benzene is not absorbed by the fibres and

consequently its use will not interfere with the determination of dry weight at a subsequent stage. On the other hand, ether is absorbed, and unless completely removed before the dry weight is determined, a reliable figure will be difficult to obtain. Consequently, as will be seen in the discussion of a later stage of the whole process, the use of ether involves extra trouble. If ether is used, however, it is preferable to wash with distilled water first and ether afterwards.

Sometimes it might be undesirable to wash the sample at this stage, as it might subsequently be required in the unwashed state in connection with some other analysis. In such a case the laboratory sample may be taken from the unwashed sample and either washed before measurement or afterwards. The same procedure is used, but it is always convenient, if possible, to carry out the washing of the whole sample as the first stage of the whole process.

(iii) Selection of a Laboratory Sample for Analysis

The laboratory sample selected for analysis from the main sample is composed of a number of sub-samples obtained by the process of zoning. In determining the size of laboratory samples to be analysed, three considerations must be borne in mind—

(1) The total weight of the laboratory sample must be large enough to permit of accurate subsequent weighing. The writer has adopted the arbitrary minimum limit of 50 mg. dry weight. It is, however, only in the case of very fine wools that this is a limiting factor.

(2) The size of the laboratory sample will also be determined by the number of zones decided upon, and by the weight of each sub-sample from each zone, having regard to reasonable size and convenience of separation.

(3) In the case of a coarse wool the total number of fibres in the sample might become a limiting factor if it were decided that it was undesirable to measure a very large proportion of the fibres. On the other hand the large proportion involving fewer measurements is usually an advantage.

The number of zones will first be decided. As has already been indicated, it is probable that 32 zones will be sufficient in the case of samples up to the limit of size dealt with in this paper, and probably will be sufficient for still larger ones. If, however, the sample whose mean fineness it is desired to determine is comparatively small, say 10 to 20 g. or less, the number of zones may be reduced, and in all probability this reduction will have no appreciable effect upon the accuracy of the result. In general, however, a reduction in the number of zones below 32 will not always result in appreciable saving of time.

It is convenient to divide the sample into a number of approximately equal pieces corresponding to the number of zones. This is not absolutely necessary, and it is possible to zone without sub-division of a sample, but sub-division is undoubtedly convenient.

A small sub-sample is now taken from each zone. Probably the most convenient way is to separate off very carefully a small piece of wool several times larger than the sub-sample required, and then by successive division to obtain the sub-sample. At first it may be useful to weigh the sub-samples roughly in order to ensure that they are of the right size and approximately equal weight, but with practice it is not difficult to judge by eye. Every

effort must be made to separate off a very small piece of wool complete from base to tip. It will be found that with practice this can be readily done, and sub-samples containing sometimes as few as 40 fibres can be obtained. It is important to avoid breakage of fibres as much as possible, and here again it will be found that with practice an extraordinary improvement can be effected. A minimum limit of 40 fibres is probably a fairly close estimate for most types of wool. In the case of a fine Merino such a sub-sample will be extremely small, and in the case of a Lincoln will be relatively large, but the apparently much greater ease of separation in the case of the Merino wool results in minimum sub-samples of very different weights for fine and coarse wools, but which turn out to contain about the same number of fibres.

It might be thought at first sight that it would be necessary to ensure the actual measurement of sufficient fibres from each sub-sample, but this is not the case. It has already been shown that the length dispersion is not appreciably affected by zoning, the purpose of which is to reduce the variability of fineness. Although it is unlikely that such a case would arise, it would not matter if the number of fibres to be measured and the number of sub-samples were in such proportion that no fibres at all were measured from some of the sub-samples.

In many wools, particularly medium and coarse wools, the number of zones and the size of the sub-samples will be the limiting factor in determining the size of the laboratory sample analysed, which might in the case of such a wool as a Lincoln attain a dry weight of 600 mg. or more.

It is advisable to determine roughly the number of fibres in a given weight of the wool. This knowledge is required for the next stage of the process, but in the present stage it may be required in case the total number of fibres were a limiting factor.

(iv) Determination of the Proportion of Fibres to be Actually Measured

In the case of a wool that is being analysed for the first time the number of fibres that must be actually measured in order to reduce the error of length sampling to the limits desired for that particular case, can only be a guess. A very accurate estimate is, of course, possible when two or three analyses have been done. A consideration of the analyses in Table X will be of assistance in deciding the number to be actually measured, and as experience of the method as applied to various wools is gained, it is possible to make a guess that will not be very far from the number subsequently found to be necessary. It is desirable to make the estimate a generous one, in case the number measured should prove to be after all inadequate and an analysis thereby wasted.

If previous analyses have been made on the same sample or on very similar samples, the estimate can of course be made with considerable accuracy. The calculation is described in a preceding section, the formula being—

$$n = \text{number of fibres to be measured,}$$
$$= \left(\frac{\text{percentage standard deviation of length}}{s_1}\right)^2,$$

including the appropriate correction (*vide* Table XIV) if the proportion measured is high, where s_1 is the limit that has been assigned as the permissible error of length sampling. The permissible error of length sampling does, of course, vary to some extent with the error of the fineness dispersion of zoned laboratory samples. It would be an excessively laborious task to

determine this latter value for many cases, but as the tables given in this paper show, with a proper system of zoning it is likely to be small. It is probable that, in order that a 5% difference between the means of duplicates should be significant with a chance of 249:1, the permissible standard error of length sampling can safely be fixed at about $\pm 1{\cdot}4$. The same chance, in the case of a 10% difference, would correspond to a permissible standard error for length sampling of $\pm 2{\cdot}8$. As results accumulate the check already described could be applied, and it would then be seen whether the permissible limits for the whole procedure were or were not being exceeded.

The number of fibres to be actually measured being settled, the total number of fibres in the laboratory sample can be roughly estimated, and the proportion of fibres to be measured is then known.

Down to a proportion of one fibre measured in twenty, the time taken in counting is not very great in comparison with the time taken in measurement, but if the proportion becomes less than one in twenty the time taken in counting becomes appreciable. In certain cases it is inevitable that the proportion should be less than one in twenty, but if this is the case the procedure should be reviewed, in order to see whether it is possible, whilst still keeping within permissible limits, to reduce the size of the laboratory sample by reducing the number of zones or by decreasing the size of the sub-samples.

(v) The Measurement of Length

It is required to determine the total length of the laboratory sample, and as already explained, this is effected by the measurement of a proportion of all the fibres contained in it. It has also been explained that it is very advisable to effect a separation, as the analysis proceeds, of the fibres into two groups according to their length in relation to the approximate mean length of the sample. The main group should make up at least 94% of the total length of the laboratory sample, and will in almost all cases make up a good deal more than this. Very short and broken fibres making up the remainder should be treated separately. An arbitrary limit can be fixed, for example, in the case of a wool with a mean fibre length of 20 cm., the lower limit might be fixed at about 9 or 10 cm. As analysis proceeds, short and broken fibres which are judged by eye to fall below this arbitrary limit are placed on one side.

The sample is analysed by drawing out the fibres one by one. If it has been decided that the proportion to be counted is one in ten, the length of each tenth fibre is measured and recorded. This process is continued until the sample is finished. In the case of the broken and short fibres, these may be placed on one side and allowed to accumulate and then from time to time, or after the main part of the sample is finished, a proportion of these are measured in the same way. The percentage error of length sampling will be greater in the case of these short fibres, but as they hardly ever contribute more than one-thirtieth of the total length of the sample, the accuracy need only be one-thirtieth of the accuracy required for the main sample, which means that if the same proportion is measured in the case of the short and broken fraction an amply high enough accuracy will be attained.

It can readily be shown that the measurement of the length of wool fibres as suggested in this paper is an operation both theoretically justifiable and easily applicable in practice, as far as any limits of accuracy contemplated in regard to this method are concerned. In the first place the length of wool fibres is not appreciably affected by humidity, etc. Nathusius (1866) states

that there is no extension in length when the fibre is wetted with water. This result is confirmed by Hirst (1922) for water and alkaline solutions. Hirst states that theoretically there should be a very small extension, but this was certainly less than 0·2%, the limit to which he was measuring.

The length of a fibre is taken to be its length when it is extended just sufficiently for all waviness to disappear and the fibre to become straight. If weights are attached to a fibre successive increases cause a lengthening until this point is reached. A considerable increase is now necessary before the fibre commences actually to stretch, so that it is not difficult to hit off the required state of the fibre when measuring it.

The writer has made a number of tests with different observers, each observer measuring and recording the length of the same fibre. It was found that agreement was remarkably close. Usually the result was stated to the same millimetre. Sometimes there was a difference of one millimetre, and very occasionally of two millimetres. No constant difference between the measurements of different observers could be detected.

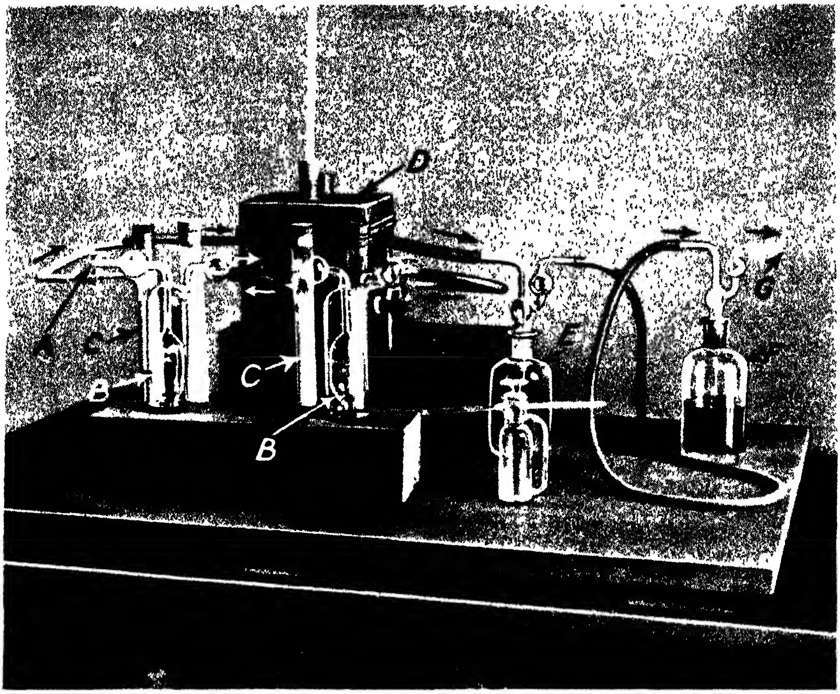
The writer uses a board covered with black velvet. On this is placed a steel ruler graduated in centimetres. The fibre to be measured is held either with forceps or with the fingers. One end is placed opposite a convenient mark, say the 10 cm. mark, and the fibre gently stretched out until all waviness is removed and it just becomes straight. The use of forceps requires little additional comment. It will be found in practice that accuracy and speed are rapidly attained. It may, however, be found more convenient in certain cases to dispense with the use of forceps or to use only one pair. If forceps are not used, one end of the fibre may be placed opposite the 10 cm. mark and held down firmly with the nail of the thumb or forefinger of the left hand. The other end of the fibre is held with the thumb and forefinger of the right hand and pulled until the fibre just becomes straight. It is then easy to hold it down very close to the tip with the thumb-nail of the right hand. The end of the fibre alongside the 10 cm. mark can then be released and the left-hand thumb-nail placed opposite and touching the right-hand thumb-nail. The remaining small portion of the fibre to the right of the thumb-nails can be stretched out by sliding the right-hand thumb-nail along it.

The criteria for determining the largest units of measurement that are permissible are given by Fisher (1928), p. 50. The unit of grouping must not exceed one quarter of the standard deviation, so that if the standard deviation of length is ± 2 cm. or more it is permissible to measure to the nearest half-centimetre instead of to the nearest millimetre. It will be found that in most of the longer and coarser wools the standard deviation does exceed ± 2. Which interval of measurement should be adopted will, of course, be immediately apparent for any sort of wool as soon as the standard deviation of fibre length has been worked out.

As analysis proceeds it is convenient to roll the fibres that have been measured under the palm of the hand on the board. In this way they become tangled and form a sort of ball, in which all the fibres stick together, so that when the sample is finished it can be handled as a unit without fear of the loss of fibres.

(vi) The Second Washing

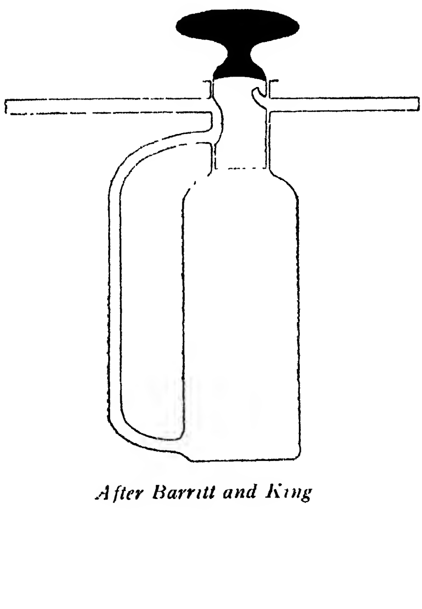
During the process of analysis it is inevitable that the sample will have picked up a certain amount of grease from the fingers, and another washing



APPARATUS FOR DETERMINATION OF REGAIN OF SMALL SAMPLES

A Air entry from atmosphere
BB Two Sulphuric Acid Wash Bottles
CC Two Calcium Chloride U-tubes
D Electric Oven with Thermometer and Regulating Resistance.
E Air Flask
F. Sulphuric Acid Trap Bottle
G Outlet to Filter Pump
H Spare Regain Bottle

After Barritt and King (Private publication)



After Barritt and King

is highly desirable. If the benzene and distilled water procedure has been followed, a single washing with benzene is sufficient. The sample is then roughly dried between filter papers and allowed to dry completely in the air.

If, on the other hand, ether is being used, rather more trouble is involved. It is necessary to use ether to remove the grease and after the ether it is necessary to use three changes of distilled water in order to remove the ether before weighing. As has already been pointed out, ether must be removed from wool fibres before they are weighed, if an accurate dry weight is to be obtained.

(vii) The Determination of Dry Weight

The amount of water absorbed by wool varies with the humidity of the atmosphere, and so great are these variations with different levels of relative humidity that it is absolutely necessary to weigh wool under standard conditions, unless only relative weights are required. In the case of the measurement of fineness described in this paper an absolute weight is, of course, necessary. The most convenient standard weight to adopt is the dry weight. A very complete procedure for obtaining the dry weight of wool is available, and is described by Barritt and King (1926). In principle the method consists in the heating of the wool to a temperature of 105° C. (permissible range 103°–107° C.) in a current of dry air. It is to be noted that although an irreversible change does take place in the wool owing to the heating, this change has no measurable effect upon the value for the dry weight. Exactly the same result is obtained if a current of dry air is passed over the wool at room temperature for an extended period. The heating really gives the same result in a very much shorter time. The illustration on page T 149 shows the type of bottle used.*

When the single stopper is in the open position a current of dry air passes through the wool from the bottom of the bottle to the top. A turn of the stopper through 90° seals the bottle. The whole apparatus is arranged as follows—

An electric oven is mounted on a board. The bottle projects into a cylindrical cavity and is supported by the side tubes which rest upon the bottom of U-shaped depressions in the sides of the oven. The oven possesses a hinged lid which closes it, leaving holes for the side tubes A thermometer projects through the lid. The temperature may be controlled by the use of a resistance, or if it is certain that the oven will be required only for the one temperature, thermostatic control would of course be still more convenient. Air is drawn through the apparatus by a water pump and is passed first through two sulphuric acid bulbs and then through two 10-in. U-tubes. The first two or three inches of the first U-tube contain granular soda lime, in order to remove any acid vapour. The remainder of the first and second U-tubes are filled with fine calcium chloride granules. The air then passes through the bottle, and in between the bottle and the water pump is interposed a sulphuric acid bottle, in order to prevent water vapour travelling back from the pump.

The stopper of the bottle is greased with a very minute trace of high-temperature rubber grease. The sample is placed in the bottle, which is then placed in the oven, care being taken that it is suspended in the middle of the cylindrical space with the thermometer bulb touching it about half-way down its length. The heating is first carried out without

* Supplied by Messrs. Standley Belcher & Mason Ltd , Birmingham.

the current of dry air, the bottle simply resting in the oven with the side tubes open. In this way the great bulk of the water is more rapidly got rid of, by shaking out the condensed droplets from the side tubes from time to time.

When it is seen that the water has more or less ceased to condense in the side tubes, the apparatus is connected up and a slow current of dry air drawn through the bottle, about two bubbles per second through the sulphuric acid bottle being a reasonable rate of flow. After a length of time that will depend to some extent on the size of the sample, and which can be estimated with experience, the bottle is removed from the oven without disconnecting it and the electric current turned off. When it is quite cold, the stopper is closed and the bottle placed in a desiccator for half an hour. The bottle is then removed from the desiccator, carefully polished with a silk handkerchief, and placed upon the pan of the balance. In 10 minutes a weighing is made. The bottle is returned to the oven, the apparatus connected up, and a further heating in a current of dry air carried out. A second weighing is taken in the same way. The process is repeated until a constant weight is obtained. With experience in the use of the apparatus it will be found quite a simple matter to get a constant weight within 0·1 or 0·2 of a milligram, though for the method under discussion such an accuracy will not often be necessary. It is, however, advisable to see that the apparatus will work to a high limit of accuracy in the first place. With experience two, or at most three, weighings should be all that are necessary.

A very great simplification of the whole procedure is possible, which results in the saving of a great deal of time. It is possible, given certain conditions, to avoid the necessity for determining the dry weight of each sample separately by using one of two modifications, of which the second is the more useful.

(1) If the dry weight of a number of samples is required these may be brought into equilibrium with the same atmosphere by exposing them together on a bench for 24 hours and then weighing in air. The first sample is then re-weighed in order to ensure that no change in moisture content has taken place during the weighings. Added certainty may be secured by exposing for another 24 hours and repeating the weighings. All are now placed in the bottle and the dry weight determined. From the relative weights in air, the dry weight of each separate sample is calculated. The number of samples that can be treated together in this way depends upon the number that will conveniently go into the bottle and also the number that can reasonably be exposed and weighed together. Twelve is probably a convenient maximum.

(2) If a piece of wool is taken that has been subjected to the standard washings it may be exposed until it is in equilibrium with the laboratory atmosphere and then divided into two portions, which are weighed. The moisture content of one portion is now determined and that of the other will then be known. The untreated portion of known dry weight can now be used as a standard sample. It is exposed together with the samples whose dry weight is required and weighed with them. Its relative weight as compared with those of the unknown samples and its dry weight being known, the dry weight of the unknown samples can be calculated. The same standard piece of wool may be used repeatedly for different lots until it becomes dirty.

It remains to examine the factors affecting the validity of these procedures and to lay down conditions governing their use, especially that of the second. The important point is, of course, how far wools of different kinds that have been subjected to the same treatment have the same moisture content when in equilibrium with the same atmosphere. The composition of wool keratin being variable within certain limits, it would be reasonable to expect some variation. Unfortunately very little comprehensive work has been done on this point, but such evidence as is available indicates that there is not a very serious variation in this respect even in dissimilar wools, if they have been brought to a standard condition by identical treatment. For example, Shorter and Hall (1924) show that scoured wools of different kinds have very similar moisture contents at various levels of humidity. Commercially scoured wools, however, are not quite comparable with purified wools such as result from the washings described in this paper. Barritt and King (1926) give figures for the coarse and fine fractions of Blackface wool and also figures for the coarse and fine fractions of mohair, the fibres having been purified much on the lines described in this paper. The results were as follows—

	Moisture Content Units per 100 units dry weight
Blackface—Fine fraction	15·66%
,, —Coarse fraction	15·62%
Mohair—Fine fraction	15·64%
,, —Coarse fraction	15·68%

These differences are certainly within the limits of experimental error, and it is interesting to find that in these cases at least fractions of the same sample of very different structure have such closely similar moisture contents.

In view of the lack of information bearing specifically on the point at issue, the writer carried out tests with six wools of very different types. All received the standard washings and were exposed together and the relative weights obtained. The moisture content of each was then determined. The results are given in the following table—

Table XI

Moisture Contents of Various Wools that have Received Identical Treatment and are in Equilibrium with the same Atmosphere

	% Moisture		% Moisture
Lincoln	12·81	Welsh Mountain	12·70
Southdown	12·00	Scots Blackface	11·72
Cheviot	12·14	Merino	12·21

Mean $= 12{\cdot}26 \pm 0{\cdot}42$

Percentage Standard Deviation (dry weight$=100$) $= \pm 0{\cdot}48$

It will be seen that the variability is by no means negligible, but as under proper conditions it is an error that may affect the result in either direction it may be treated statistically on the same lines as those errors previously discussed. Assuming a percentage standard error from this source of $\pm 0{\cdot}5$, it is small compared with the others, especially the error of length sampling.

Let S = total percentage standard error.

,, s_1 = percentage standard error of mean fibre length.

,, s_2 = percentage standard error of fineness dispersion (including other errors of determination).

and let s_3 = percentage standard error of determination of dry weight.

Then $S=\sqrt{s_1^2+s_2^2+s_3^2}$
Suppose that $s_1=\pm 1\cdot 4$, $s_2=\pm 0\cdot 8$, and $s_3=\pm 0\cdot 5$. Omitting s_3, S is $\pm 1\cdot 61$, and becomes $\pm 1\cdot 69$ if s_3 is included. The difference is rather small but by no means negligible. A slightly higher standard of accuracy would be required in respect of the other errors, notably of course s_1, which is under control, in order to compensate for the introduction of s_3.

It is true that s_3 might assume the nature of a constant error if it were the case that two wools were being compared that had different and characteristic moisture contents. Nevertheless it seems to be justifiable to employ the simplification even if a 5% accuracy is required, in view of the relatively small size of s_3 (if a 10% accuracy only is required, there is no question of its use being fully justified). Besides, such figures as are available make it very doubtful whether different moisture contents under the same humidity conditions can be related in any simple way to difference of structure or type of wool.

The writer would suggest the following procedure. Samples of, say, a dozen different types of wool are taken and washed in the usual way. They are then mixed as thoroughly and intimately as is possible. The mixed sample is spread out and allowed to come into equilibrium with the laboratory atmosphere. Duplicate small samples are withdrawn for determination of dry weight and they as well as the wool remaining are weighed. Their dry weight is then determined and the dry weight of the remainder of the wool is calculated. A portion of the remainder is taken to act as a standard sample and this as well as the rest is exposed and weighed in the usual way. The wool that remains, which represents the bulk of the sample, is stored in a bottle. When the standard sample has been used a number of times and tends to become dirty, it is thrown away and a fresh portion taken from the wool in the bottle, the fresh portion that is to become the standard sample and what now remains being exposed and weighed as before. This process is repeated until all the wool in the bottle is used up. Of course the dry weight of what remains in the bottle must be marked on the label and this figure altered each time a fresh standard sample is withdrawn.

From every point of view it is desirable to fit up the standard apparatus described for determining the dry weight of wool, as absolute weights are required for a number of purposes, but it is possible to estimate the dry weight in another way. The writer carried out a number of experiments in which wool was simply placed in a glass dish in a desiccator over either phosphorus pentoxide or concentrated sulphuric acid. It will be found, if this method is employed, that as soon as the lid of the desiccator is removed the wool commences to pick up water at a rate which is initially extremely fast. A special procedure must be adopted. The air weight of the sample in the desiccator is taken before it is put in, so that the dry weight to be expected will be approximately known. A tared dish is placed on the balance and weights added corresponding to slightly more than the expected dry weight of the sample. Using the second hand of a watch, the lid of the desiccator is removed at zero time. The wool is placed on the tared dish with forceps and a weighing obtained as quickly as possible. It is convenient to put on the balance a slightly greater weight than the weight of the dish and wool, and to allow the balance to swing until it is just swinging evenly. The weight and time are noted down. Slightly more weight is put on and a second weighing obtained, and in the same way a third and fourth weighing. If

the operation is carried out speedily the first weighing may be obtained in as short a time as 30 seconds. In any case it should be obtained in 60 seconds or very slightly more. The subsequent weighings may conveniently be taken at intervals of 30 to 60 seconds. If the four weighings are now plotted against time on squared paper they will be found to join up into a smooth curve which can be extrapolated back to zero time. The weight of the wool at the moment of the opening of the desiccator is then ascertained with considerable accuracy. As the result of a number of experiments it was determined that wool reached an equilibrium in about four days, so that if the sample is left in the desiccator for a week it may safely be assumed to have reached its minimum weight. Tests were carried out to compare the standard method and the desiccator method. The dry weight of a number of samples was determined first in the desiccators and subsequently by another observer using the heating and dry air method, and in all cases the difference was well within the experimental error. No difference was found between phosphorus pentoxide and concentrated sulphuric acid.

If, therefore, it were only desired to make comparatively few analyses, it would be possible to obtain the standard samples for comparison, as already described, using the desiccator method, but it should be again emphasised that the first method described is to be regarded as standard, and is speedier and more convenient. If a large number of determinations have to be done, large numbers of desiccators would be necessary, owing to the length of time that the samples must be left in them, and both phosphorus pentoxide and concentrated sulphuric acid used in this way are rather unpleasant and dangerous substances.

10—A NOTE ON KEMP

In most fleeces are to be found fibres which are known as "kemp." These fibres are distinguished by their relative shortness, extreme coarseness and brittleness, and also because they appear dead white in colour owing to the fact that the bulk of the fibre, the medulla, is a meshwork containing air. It is usually accepted that these fibres are a remnant of the primitive outer protective coat of the sheep, whereas the bulk of the fleece is a development of the primitive inner warmth-retaining coat. This argument has been previously developed by the writer (1926) and it was pointed out that the most fundamental difference between kemp fibres and ordinary wool fibres lay in the method of growth. Kemp fibres have a comparatively limited period of growth, at the end of which time they are shed. Wool fibres, in the case of the modern improved breeds, are not normally shed but grow on continuously. If they are shed the shedding takes place at a different time from that of the kemp. In the paper mentioned it was pointed out that a separation into a kemp and non-kemp fraction was readily practicable, and on this was based a method for the estimation of the proportion of kemp in a sample by weight.

It would probably be true to say that kemp fibres, though perhaps only a very few, could be found in the fleece of any sheep, but it is only in certain breeds, especially mountain breeds, that they occur in any considerable proportion. The great majority of the samples analysed, for which the results are given in the present paper, contained no kemp, or at most one or two fibres. If, however, samples were being analysed for fineness which did contain kemp, there is a very strong case for treating the kemp fraction entirely separately from the ordinary wool fraction. It has been already

pointed out that the kemp fraction is derived from a fundamentally distinct coat of the sheep, and the writer has been able to make a number of observations, which it is hoped shortly to publish, all of which tend to show that the characteristics of the kemp fraction and of the non-kemp fraction vary independently. Accordingly the best procedure during the analysis of a sample which contains kemp is to set on one side the kemp fibres, estimating these as a given proportion of kemp, in which case the figure for fineness refers to the non-kemp fraction only. To include the kemp fibres together with the others during the determination of fineness obscures the true characteristics of the sample, and is totally unnecessary, as a separation can readily be effected. To include the kemp fibres is therefore an undesirable procedure, both on theoretical and practical grounds. As has already been stated, in the great majority of the samples treated in this paper no kemp fibres at all were found, but in the one or two cases where kemp did occur, the figures refer to the non-kemp fraction.

11—A BRIEF CRITICAL EXAMINATION OF THE PROPOSED METHOD AND A COMPARISON WITH OTHER METHODS

In a recent paper Krauter (1929) gives an extremely complete account of the various methods that have been used for measuring the fineness of wool. For a full account the writer would refer to this paper. The important methods used may be simply classified—

(1) By far the most widely used method involves the magnification of fibres and a direct measurement of their diameter. Numerous refinements and modifications of this principle have been employed, e.g., the projection of the image on to a screen, the measurement of cross-sections, etc.

(2) The use in some form of extremely accurate calipers was practised as long ago as 1831, and has recently been developed by Burns and Koehler (1925).

(3) An optical method involving the diffraction of light by fine bodies, on the principle of the eriometer, was used by Dolland in 1811 and much developed by Thomas Young in 1834. It has recently been employed by Ewles (1928).

(4) The principle of weight per unit length, or length per unit weight, which is employed in the present paper, was, according to Krauter (1929) in use in 1826. It was employed by Barker and King (1926) in connection with the microbalance, and suggested for raw wool by the writer (1927). Its use for tops was described by Wilkinson (1915) and Krauter (1929). The necessary distinction between methods for tops and methods for raw wool is discussed in a later section.

With regard to the optical method of Young and others, the writer does not propose to discuss this further; criticism must be left to the physicist.

The first point to consider is that of the information provided. A single wool fibre is of variable cross-section along its length and a complete statement of its fineness would involve a large number of measurements of cross-sectional area which could then be stated as a mean and standard deviation. To replace cross-sectional area by mean diameter would be in practice a rather less complete statement. A sample of wool is made up of a large number of fibres and a complete statement would involve a mean figure and a figure for the variance for each fibre. If the microbalance is used a mean figure is obtained for the weight-length relation of each fibre and it would undoubtedly

be necessary to make a great number of diameter determinations in order to obtain as accurate a measure of the mean fineness of a fibre, but on the other hand no estimate of the variability along single fibres is possible. The result is now a mean figure for the sample, the variance being the distribution of the mean finenesses of whole fibres about this mean. If the method of the present paper is used, a mean figure for the sample is obtained but no estimate of the variance in any form. The single figure for mean fineness as given by the method of this paper is probably sufficient for many experimental purposes, especially if supplemented by measurements of other and related characteristics obtained in other ways. The writer would suggest its use even if some estimate of variability were also desired.

If wool fibres were solid, perfectly cylindrical, homogeneous rods of uniform specific gravity, it would be possible to convert mean diameter into centimetres per milligram and *vice versa*. Length per unit weight is inversely proportional to the area of cross-section and inversely proportional to the square of the diameter. As a matter fact the specific gravity of dry wool is very constant and the value of 1·30 may be accepted, *vide* King (1926). As long, therefore, as the fibres do not include an air-filled medulla, results obtained in either form may be converted into the other.* Coarse fibres, however, often do include an air-filled medulla, and frequently the amount of this contained air is large. Barker and King (1926) use the disproportion under these circumstances between direct diameter measurements and the weight-length relation as the basis for an ingenious method of estimating the proportion of contained air. In the case of fibres containing air it is perhaps a matter for argument which measurement is the more useful. It is to be noted, however, that as the trade estimation of "quality," which is largely based on fineness, depends to that extent upon a weight-length relation, the direct diameter measurement will give results less readily related to such practical considerations.

At present the only methods that can give the complete information mentioned in the first place are the microscopic and caliper methods. In practice, however, they are not usually employed in this way. The diameter or cross-sectional area of each fibre is measured, usually at one, sometimes at two or more points, and a mean and standard deviation may be calculated. These values are sometimes treated as though each represented a complete fibre; for example, a few specially large fibres are noted, whereas they may be specially large portions of fibres. It would probably be fairer to state that estimates of variance obtained in this way represent the variability of a sample considered as a single length of continuous fibre measured at various points. It is to be noted that the information obtained by the use of the microbalance is not contained in that provided by diameter measurements of the usual kind. It is possible that either might be the more suitable in a particular case.

A further point to be considered in connection with the form in which information is provided is that length per unit weight is readily related to other dimensional characteristics of the fleece that are of importance, e.g.—

$$\underset{\text{(mgs. per sq. cm.)}}{\text{Weight per unit area}} = \frac{\text{Density (no. of fibres per sq. cm.)} \times \text{average length (cms.)}}{\text{Length per unit weight (cms. per mg.)}}$$

It will be pointed out at the end of this section how it will be possible to extend the method in such a way as to provide information on these other points by carrying out a single series of observations requiring little more time than those described in this paper for fineness alone.

* The mean value obtained by the gravimetric method is weighted. See note at end of paper.

The next consideration is that of the accuracy possible using this method, especially as contrasted with direct diameter measurement. The main obstacle in the way of accuracy in the case of the present method is the difficulty of sampling, and of course this difficulty is present in the case of other methods too. The errors involved have been fully discussed and it has also been shown that as regards subsequent operations any errors are very small, while in the case of the error of length sampling and the error of short methods of dry weight determination these are controllable and can be reduced to any desired limit. Especially is it the case that there is little chance of constant errors or of errors of any magnitude that are outside control or whose effect cannot readily be determined.

In the case of direct diameter measurement or of the measurement of cross-sections the position is a little more complicated. It is probably true that many possible errors may be eliminated, but to do so requires considerable refinement of technique.

(1) As has previously been pointed out, wool, a colloidal substance, adsorbs various liquids, including water, and this adsorption, while it has no appreciable effect on the length, has a very marked effect upon diameter. It is true that a dehydrated wool fibre in Canada balsam exhibits its true dry diameter, but care must be taken that the technique employed is such that it is the true diameter that is being measured. This consideration might apply to the preparation of cross-sections during which preparation the treatment of the fibres is vigorous.

(2) If cross-sections are prepared it is of the utmost importance that the fibres should be cut accurately at right angles to their length, also that damage to the fibres prior to cutting should be avoided. It requires very careful manipulation to ensure that the cutting is not oblique.

(3) The weight-length method averages out the fineness for the whole length of each fibre contained in the laboratory sample. It is difficult to ensure that diameter measurements, whether microscopic or caliper, shall include the whole length of the fibres. If measurements are made only on the middle portion considerable error may be introduced, as the ends are commonly finer. This again is a difficulty that can probably be surmounted by suitable technique, but the avoidance of which again involves additional complications.

(4) A number of possibilities of error are involved in the actual measurement. The edges of the fibre may not appear parallel in the image, and the serrations due to the cuticular scales may appear so deep as to be of appreciable size relative to the diameter of the fibre. Fibres are seldom circular in section and it is possible that with ordinary methods of mounting the larger diameter is more frequently presented for measurement. Wool fibres often exhibit small, much thickened, or much reduced portions, both occurring naturally and as the result of damage. It is difficult to include or exclude such portions and still to observe the conditions of random sampling. Various devices have been adopted to overcome some of these possible errors, but as before they involve very considerable complications in technique. For example, in connection with some diameter measurements by the writer's colleague, Mr. A. T. King, referred to later in this section,

each fibre was measured at either five or ten points equally spaced along the length visible in the microscopic field. Alternatively, it is possible to measure the area of the image of a section of fibre and calculate the mean diameter of that section.

Projecting the image on to a screen allows of much refinement of technique and the difficulty with the micrometer eyepiece is avoided, that the unit of measurement may be far too large in comparison with the diameter measured.

In the case of micrometer calipers, apart from the probable effect of different levels of humidity, the calipers must compress the fibre to an unknown and probably variable degree. It is known that measurements obtained by calipers are in fact smaller than those obtained microscopically.

If it is assumed that these difficulties can be overcome and measurements obtained which truly represent the sample with an accuracy sufficient for the purpose in mind, it is now possible to make some comparison between the weight-length method and the direct diameter methods with regard to the number of fibres that have to be measured. The problem is the same, viz., to estimate the mean fineness of a sample with a required degree of accuracy. From the point of view of diameter measurements the sample is a population not of fibres but of an infinitely large number of points along a large number of fibres. If a perfect mixing has been secured in the sense that the points measured are a perfect random sample of the whole population, a mean and standard deviation may be calculated, and then a percentage standard deviation. It must be specially borne in mind that as length per unit weight is inversely proportional not to the diameter but to the square of the diameter, the accuracies corresponding to 5%, 10%, and 20% for weight-length measurements are 2½%, 5%, and 10%. The corresponding standard errors are therefore only half as large. The accuracy assumed right through this paper is that a 5% difference between the means of duplicates should be exceeded by chance not more often than once in 250 times, the corresponding percentage standard error being $\pm 1{\cdot}74$. The same accuracy for diameter measurements would assume that a 2½% difference between the means of duplicates is exceeded by chance not more often than once in 250 times, the corresponding percentage standard error now being $\pm 0{\cdot}87$. In order to fulfil this condition for the means of successive laboratory samples of diameter measurements drawn from the same population under perfect conditions of sampling, it is necessary to make sufficient measurements to reduce the percentage standard deviation to $\pm 0{\cdot}87$.

As before—

$$\text{Percentage standard error} = \frac{\text{percentage standard deviation}}{\sqrt{n}}$$

and Number of fibres to be measured $= n$

$$= \left(\frac{\text{percentage standard deviation}}{0{\cdot}87}\right)^2$$

If, however, the mixing is not perfect, i.e., the conditions of random sampling are not being observed, an additional sampling error is introduced that is related to this error already mentioned in the usual way. It would be possible to estimate with some closeness the efficiency of the method of sampling employed if a considerable number of successive determinations

were carried out from the same sample. If these included, say, 6,000 or more measurements, the estimate of the mean and standard deviation for the whole sample would be a fairly accurate one. It could then be seen whether the means of successive laboratory samples were in fact distributed with the standard error calculated from the standard deviation, or if this were exceeded.

Let S =percentage standard error of distribution of means of successive laboratory samples.

,, s_1=percentage standard error of measurements made on laboratory sample.

,, s_2=additional percentage standard error due to imperfect mixing.

Then $s_2=\sqrt{S^2-s_1^2}$

It is to be noted that s_2 includes not only the error involved in the selection of the laboratory sample but also the error, if any, involved in the choice of the actual portions for measurement of the fibres measured.

The writer is not aware of any published figures that would allow of any estimate of s_2 being made, but it is certain that in the case of some procedures that have been used it must be very large indeed, far too large for any reasonable difference to be considered significant. In other cases the mixing has been much more thorough and the error may be quite small. The same considerations apply as apply to the zoning in the case of weight-length measurements, but actually it is possible in connection with diameter measurements to obtain a very perfect mixing as regards the fibres or more especially pieces of fibres mounted for measurement. Of course there is still the question of selecting the precise point measured, but this is a possible error that could only be reasonably estimated by direct experiment. A very good mixing is obtained by a method employed by Dr. J. E. Duerden. The full details have not been published and the writer is indebted to Dr. Duerden for the description. As a preliminary a system of zoning is employed much on the lines described in this paper. The small locks are laid out and a very small piece taken from each. These small pieces are cut into ⅛-inch lengths so as to get a mixing in relation to variability along the fibres in addition. The cut pieces are washed in a beaker, during which process a thorough mixing of the pieces takes place. A portion is then withdrawn and mounted for measurement.

In order to make the comparison as fair as possible to direct diameter measurement, let it be assumed that the preliminary difficulties have been satisfactorily overcome and that the mixing has been so perfect that it is possible to work almost up to the full limit for the percentage standard error, viz., $\pm 0{\cdot}8$ instead of $\pm 0{\cdot}87$. In the following table figures are given for two samples whose diameter was measured directly by Mr. A. T. King, and the weight-length relation measured by the writer. It is to be noted that Mr. King's figures are based on the measurement of each piece of fibre at either five or ten points along its length as shown on the screen. This undoubtedly reduces the variability and if single measurements had been taken the number of observations that would have to be made would necessarily be considerably greater. Figures are also worked out from the results of Duerden and Bosman (1926) and in this case figures obtained by the writer for wools of similar fineness are given for comparison. In the case of Duerden and Bosman's Merino 60's two very large measurements are excluded from the calculation as they were probably kemp fibres.

Table XII

Wool	Diameter Measurements: Mean Fineness μ	Diameter Measurements: Standard Deviation $\pm$	Weight-length Measurements: Mean Length	Weight-length Measurements: Standard Deviation $\pm$	No. of Fibres to reduce % S.E. to correspond to 5% accuracy for weight-length method and equivalent accuracy for diameter measurement: Diameter Measurements	No. of Fibres …: Length Measurements
Merino 60's, uneven ... (Duerden & Bosman)	22·9	6·26	—	—	1,165	—
Merino 60's ... ... (Roberts)	—	—	12·2	1·47	—	64
Merino 70's, even ... (Duerden & Bosman)	17·8	3·05	—	—	462	—
Merino 70's ... ... (Roberts)	—	—	10·9	1·27	—	66
Merino 60's	22·3	3·21	11·3	1·30	327*	61
Lincoln, very uneven ...	44·7	11·23	27·1	5·60	983*	280†

* Each measurement a mean of 5 or 10 measurements on a small portion of a single fibre.
† Proportion of 1 in 4 measured.

If an accuracy were sufficient of 10% for the weight-length method with a chance of 249:1, corresponding to an accuracy of 5% with the same chances for diameter measurement, the number of fibres that would have to be measured would be a quarter of those given in the table in each case.

It must again be emphasised that the number indicated for the diameter measurements assumes almost perfect sampling, while in the case of the weight-length figures the permissible limit of the standard error of length sampling is fixed at $\pm 1{\cdot}4$, the total permissible error being $\pm 1{\cdot}74$, so that a considerable margin is left for the error of fineness sampling and for the error involved in a shortened method of dry weight determination.

The advantages of the weight-length method for obtaining a value for mean fineness (without any measure of variability) may be summed up as, first, the greater simplicity of length and weight as properties of fibres, and secondly, the much smaller variability of length, which means that fewer fibres need be measured.

Wilkinson (1915) describes a weight-length method for estimating the mean fineness of tops, involving the cutting of a large number of fibres to uniform length, then counting and weighing. The procedure suggested in connection with the cutting, the fact that no allowance is apparently made for any natural curl left in the fibres, and also the fact that in the weighing no allowance is made for variation in humidity, make it probable that what was aimed at was a relatively very speedy method of moderate accuracy. Krauter (1929) describes a development of this method involving far more elaborate technique, and permitting of a high standard of accuracy.

It would undoubtedly be very convenient to cut the fibres to uniform length in the case of a raw wool, but it must be pointed out that the problem in the case of raw wools, as Krauter also indicates, is quite different. When

a raw wool is converted into a top by the processes of carding and combing two effects have especially been produced. In the first place the fibres are arranged more or less parallel and in the second place they have been very thoroughly mixed. During the carding and combing a considerable amount of inevitable breakage has occurred and a fraction consisting of short, broken pieces, known as the noil, is separated off so that the top does not contain all the raw wool. The noil is finer than the corresponding top. The fibres in a lock of raw wool are not quite parallel to each other and if they had to be combed out in order to permit of straightening and cutting a lot of breakage would occur, as in the commercial processes mentioned, and the short broken pieces would be finer than the main fraction. It is also true that a lot of the sampling difficulties inherent in raw wool no longer exist in the case of a top, owing to the thorough mixing it has undergone. Accordingly a procedure involving cutting is quite suitable in this case, but it is very difficult to see how it could be applied to a raw wool.

With regard to the speed of the method, this must of course vary with the individual worker concerned, so that the writer does not propose to give figures. The time involved in actual counting and measurement may, however, be fairly readily estimated from the figures given. There is one important consideration that the writer would point out in connection with any judgment on the convenience and speed of the method. Several other important characteristics of the fleece can be measured during the course of practically the same operations as those described in this paper for fineness only. For example, if the sample, or samples, are taken from known areas of skin, the following quantities may be measured with very little modification of the procedure--

(1) Weight of wool per unit area.
(2) Number of fibres per unit area.
(3) Mean length of fibres.
(4) Mean weight of fibres.
(5) Combinations of the above, e.g., the relation between the sum of the cross-sectional areas of fibres and the area of skin on which they grow.

It is hoped that these further measurements will be described in subsequent papers. For the present the writer would merely point out that the simple procedure described in this paper is capable of giving a great deal more information than just mean fineness alone.

12—APPENDIX

Table XIII
Equivalent Values

Centimetres per milligram	Microns	Ten-thousandths of an inch	Centimetres per milligram	Microns	Ten-thousandths of an inch
50	44·3	17·4	200	22·1	8·7
60	40·4	15·9	225	20·9	8·2
70	37·4	14·7	250	19·8	7·8
80	35·0	13·8	275	18·9	7·4
90	33·0	13·0	300	18·1	7·1
100	31·3	12·3	350	16·7	6·6
125	28·0	11·0	400	15·6	6·2
150	25·6	10·1	450	14·8	5·8
175	23·7	9·3	500	14·0	5·5

Note—The density of dry wool is taken as 1·30. If the fibres contain an air-filled medulla, the values for length per unit weight and mean diameter no longer correspond. This will particularly apply to coarse wools.

Table XIV

Correction Table for Standard Error of Fibre Length if Proportion Measured is High

Proportion Measured	Correction Factor	Proportion Measured	Correction Factor
1 in 4	0·866	1 in 13	0·961
1 ,, 5	0·896	1 ,, 14	0·964
1 ,, 6	0·913	1 ,, 15	0·966
1 ,, 7	0·926	1 ,, 16	0·969
1 ,, 8	0·936	1 ,, 17	0·970
1 ,, 9	0·943	1 ,, 18	0·972
1 ,, 10	0·949	1 ,, 19	0·974
1 ,, 11	0·954	1 ,, 20	0·975
1 ,, 12	0·958		

Note—The full formula is $\frac{\sigma}{\sqrt{n}} \times \sqrt{\frac{N-n}{N-1}}$. If the observations form a high proport of the total population the difference between this value and that obtained by using $\frac{\sigma}{\sqrt{n}}$ becomes appreciable. Within the limits of the numbers of fibres contained in a laboratory sample of any wool, say 400–4,000, the correction factors above are sufficiently accurate to the number of places of decimals given in this paper $\frac{\sigma}{\sqrt{n}}$ may be calculated in the ordinary way and then multiplied by the appropriate figure.

13—ACKNOWLEDGMENTS

During the course of this work, which has covered a considerable period, the writer has been indebted for much assistance and wishes to express his most grateful thanks; on the statistical side to Dr. R. A. Fisher of Rothamsted for his help and criticism, and also to Mr. G. Smeal of the University of Leeds, and to Mr. Arnold Frobisher of this Association; to Mr. A. T. King and Mr. H. R. Hirst of this Association for their help in connection with questions of the washing of wool, its moisture relations, specific gravity, and the like; to Professor G. W. Robinson of the University College of North Wales, Bangor, for helpful general criticism; to Professor F. A. E. Crew of Edinburgh University, at whose Department this work was commenced; to Dr. S. G. Barker, Director of Research of this Association; and to the writer's assistant Miss M. Gurney, for most careful and accurate work in connection with many of the analyses recorded in the paper.

On behalf of the British Research Association for the Woollen and Worsted Industries the writer wishes to express high appreciation for the financial support given by the Empire Marketing Board, without which provision the great mass of work involved could not have been carried out within any reasonable time. The writer hopes that this paper may be regarded as a beginning in the task that the Association has set out to perform with the generous assistance of that Board.

14—SUMMARY

(1) It is necessary to measure the characteristics of fleeces so as to state in figures the difference between fleece and fleece. Especially is this desirable in connection with breeding and feeding experiments. The methods used must for several reasons be developed with the biological purpose kept in view. The level of accuracy attained will vary with the purpose for which the measurements are required and the potentialities of the method, but the important consideration is that it must be controlled accuracy, with known limits of error.

(2) Fineness is one of the most important characteristics of wool and in connection with observations on the sheep the average fineness of a sample or portion of the fleece is the most important figure to be obtained. In the present paper attention is confined to this problem; the question of extending the work to form an estimate of the entire fleece is left over for a future paper.

(3) The method suggested involves the selection of a laboratory sample from the sample whose mean fineness is to be determined, and the determination of the total length of the fibres contained in it. This is followed by a determination of the dry weight of the laboratory sample and the fineness is stated in centimetres per milligram.

(4) It was found that fineness may vary within extremely wide limits over relatively very small areas of skin. A system of zoning must be adopted by which the laboratory sample actually analysed is made up of a large number of very small pieces taken from all over the main sample.

(5) In order to form a sufficiently accurate estimate of the total length of the laboratory sample it is unnecessary to measure the length of every fibre. Owing to difficulties in the random sampling of fibres it is necessary to adopt a process of tabbing. All the fibres are pulled out one by one and all counted but a proportion only are measured, every eighth, tenth, twentieth, etc., as the case may be. It is shown that this process of tabbing yields results entirely equivalent to those of random sampling.

(6) A full statistical study shows that it is possible to lay down definite and controllable standards of accuracy for the whole process. The analyses may be performed in such a way that any selected percentage difference between the means of duplicate analyses is significant with any selected chance. The limit of accuracy employed in this paper is that a 5% difference between the means of duplicates should be significant with a chance of 249:1. It is specially noted that as the measure of centimetres per milligram is inversely proportional to the square of the diameter, a 5% accuracy corresponds to a $2\frac{1}{2}$% accuracy for diameter measurements. This is probably the greatest accuracy that is required in practice, or that, owing to the difficulties of sampling, is readily attainable in any ordinary case.

(7) A number of results for various kinds of wool are given which show in detail the order of magnitude of the size of laboratory samples in any particular case, the number and proportion of fibres that it is necessary to count, etc. It is hoped that these results will assist in the application of the method to any particular wool with a minimum of preliminary experiment.

(8) Full details are given of each step in the process of analysis.

(9) It is to be noted that the suggested method gives simply a mean figure without any measure of the variability of fibres. If this additional information is required recourse must be had to diameter measurements of the ordinary type or some analogous method. It is pointed out that as a means of determining average fineness the suggested method possesses advantages over diameter measurements of the ordinary type. These advantages essentially depend upon two considerations. In the first place length and weight are much simpler attributes of fibres than diameter, hence there are fewer pitfalls in connection with technique. In the second place fibre length is very much less variable than fibre diameter, so that in order to attain the same accuracy fewer measurements are required.

(10) Although the present paper deals only with mean fineness, it is pointed out that a number of other important attributes of the fleece can be measured

with very few modifications during the course of the same procedure as that described in the paper.

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[After this paper had gone to press it occurred to the writer that an important distinction between the mean fineness of a sample, based on diameter measurements, and the mean fineness based on the weight-length method, had not been sufficiently emphasised. Using the weight-length method, each fibre contributes to the result in proportion to its weight. On the other hand, in diameter measurements of the ordinary type, when the same number of measurements are made on each fibre, the contribution of every fibre is the same. Consequently, the mean fineness of a sample, as determined by the two methods, will not necessarily correspond. With some techniques used in connection with diameter measurement, such as that of Duerden, each fibre contributes in proportion to its length.

If now the mean of two or more determinations is required, and the unweighted arithmetic mean is taken, the underlying assumption is that in the case of the weight-length method, equal weights of wool are being considered together, while in the case of diameter measurements of the ordinary type it is equal numbers of fibres that are being considered.

If a weighted mean is required, as in the case when wools are blended, the fineness of each constituent mass being known, the weighting on the weight-length method must be in proportion to the weights of the constituent masses, while in the case of diameter measurement methods the weighting must be in proportion to the number of fibres contained in them.]

9—THE DRY WEIGHT OF COTTON

By George Forrest Davidson, B.Sc., and Sydney Alfred Shorter, D.Sc.

INTRODUCTION AND SUMMARY

It is generally recognised that the determination of the amount of moisture in a textile material such as cotton is not an absolutely definite process. Thus it is known that the apparent "dry weight" obtained with an ordinary drying oven decreases as the temperature is raised. There is, however, little definite information as to the relation of such apparent dry weights to each other, or to the true dry weight.

Previous Work

Renker[6] recognised that different "dry weights" were obtained on heating sulphite pulp according as ordinary or artificially dried air was used, and that the difference became small at temperatures above 110° C. He found that "pure normal" cotton, dried over phosphorus pentoxide at 35° C. and then heated in dry air to 125° C., suffered no further loss either of hygroscopic or constitutional moisture; above 125° C. small losses by decomposition were noted. Later, Dietz[2] showed that the ordinary commercial method of drying, using ordinary air, gave a lower regain for textile materials than the method of drying in a stream of hot dry air under reduced pressure. For carded wool the two methods gave regains of 10·41% and 10·92% respectively, and very similar results have recently been obtained by Barker and Hedges.[1] Hönig[3] has compared the weights obtained by heating various cottons, raw and solvent-extracted, in a vessel which was kept partially evacuated by a pump. On raising the temperatures, the cotton was found to lose weight rapidly at moderately high temperatures, then more slowly between 100° C. and 120° C., and finally as the temperature was raised to 180°, the loss became rapid again. The first and last periods in this experiment appear to correspond respectively to the loss of hygroscopic water and to permanent loss, while the slow loss in the middle is probably due to the fact that most of the hygroscopic moisture has been driven off, whilst the permanent loss has not yet become rapid. Hönig found that the fat content of cotton, as measured by extraction with petrol ether and alcohol, was reduced by heating.

Nelson and Hulett[4] maintained that all the absorbed moisture is not removed in drying in vacuo over phosphorus pentoxide at room temperature, but is progressively removed by raising the temperature during the evacuation. They heated absorbent cotton wool at various temperatures up to 238° C. in a high vacuum and collected the moisture in a tube cooled in solid carbon dioxide. The temperature-regain curve showed a break at 218° C., which they took to be the temperature at which decomposition of cellulose becomes rapid, and they obtained the "true" regain by extrapolation of the lower part of the curve to 250° C.

Obermiller and Goertz[5] measured the residual moisture left in cotton after drying with hot air of known moisture content, thus obtaining material for the construction of desorption isotherms at low humidities and high temperatures. Their estimate of the hygroscopicity of cotton under such conditions is much in excess of that deduced in the present paper.

Present Work

The results of the present study on the drying of cotton may be summarised as follows—

1. *The True Dry Weight*—This may be defined as the constant weight obtained by prolonged exposure at room temperature to the dry atmosphere produced by phosphorus pentoxide. This is a reproducible magnitude. If any hot air drying process gives a lower value, subsequent low temperature drying over phosphorus pentoxide gives less than the true dry weight, indicating the permanent loss of water or other material.

2. *The Time Factor in Drying*—Cotton subjected to the action of hot air continues to lose weight for days or even weeks. Under conditions of commercial testing the rate of loss becomes very slow in a few hours, and if the weighings are conducted at definite intervals to a definite degree of accuracy, a stage is finally reached when two consecutive weights do not differ. The time taken to reach this stage of apparent constancy of weight is obviously the longer the more accurate the weighing or the greater the interval between weighings, but within the limits of ordinary practice the criterion of apparent constancy may be varied without having any appreciable effect on the weight.

3. *The Effect of the Temperature of Drying*—If air which has been artificially dried is used to dry cotton, the dry weight obtained is independent of the temperature over a wide range. This weight is, of course, the true dry weight. At temperatures above 100° C., however, a smaller dry weight is obtained, and this is repeated as the result of a subsequent low temperature drying. On the other hand, if cotton is heated by undried air, the dry weight obtained at moderately high temperatures is greater than the true dry weight. This is due to the fact that heating ordinary air does not deprive it of its moisture, but merely increases the amount required for saturation, and so decreases the relative humidity. As the temperature is raised, the relative humidity becomes less and less, so that the amount of residual moisture left in the cotton decreases. At the same time the permanent loss increases, and ultimately, when its effect counterbalances that of the residual regain, the apparent dry weight becomes less than the true dry weight.

4. *The Effect of the Hygrometric State of the Air*—Since a sample of cotton dried with ordinary air contains a certain amount of "hygroscopic moisture" dependent on the temperature and relative humidity of the air in the oven, and since this relative humidity depends on the state of the air drawn into the oven from outside, it follows that the apparent dry weight will vary with the atmospheric conditions prevailing at the time. The dry weight will be larger or smaller, according as the partial pressure of water vapour in the outer air is high or low.

5. *The Difference between Bleached and Unbleached Cotton*—The permanent loss at high temperatures is much greater with unbleached than with bleached cotton. It is therefore associated mainly with the non-cellulosic constituents of the cotton.

6. *The Correlation of Different Apparent Dry Weights*—The apparent dry weight is equal to the true dry weight *plus* the residual regain *minus* the permanent loss. It is possible, by means of observations conducted at different temperatures and external humidities, to determine separately the residual regain and the permanent loss. Thus cotton, bleached or raw, dried in an oven at 100° C., has a regain of about 0·25% in summer (when the moisture content of the outside air is high) and about half that in winter. At this temperature the permanent loss is extremely small. At 130° C. the residual regain is very small, but the permanent loss of raw cotton is about 0·2% after a few hours heating, whilst that of bleached cotton is negligible.

EXPERIMENTAL DETAILS

Methods for Determining the Dry Weight

The following five methods were used for finding the dry weight of different samples—

1. *The Desiccator Method*—The samples, contained in weighing bottles, were placed in a desiccator containing phosphorus pentoxide, and the desiccator was evacuated by means of a filter pump. With 6 to 8 gm. of cotton in each bottle, four to six weeks' drying was required to obtain a constant weight. Such a constant weight is reproducible, after allowing the material to pick up water again, and may be regarded as the true dry weight.

2. *The Commercial Oven Method*—In this method an ordinary form of commercial drying oven was used. This consisted essentially of an upright double-jacketted cylinder, through which a current of air, pre-heated by electric heating coils, was blown by means of an electric fan. The cotton to be dried was contained in a wire basket suspended from the arm of a balance capable of weighing a kilogram of cotton to the nearest 0·02 gm. The cotton could thus be weighed at intervals without being removed from the oven, the fan being temporarily stopped. A thermometer at the bottom of the oven indicated the temperature of the incoming air, and one near the top that of the outgoing air. During the earlier stages of the drying the temperature indicated by the top thermometer was appreciably lower than that indicated by the bottom one, but the two temperatures approached within a degree or two at the end of the drying. The annular space between the inner and outer jackets was filled with cotton waste to minimise the loss of heat, and a mercury temperature regulator was fitted in the lower part of the oven, so that it was possible to keep the bottom thermometer constant to within 1° C. on either side of the desired temperature.

In weighing cotton in the hot oven, an error is introduced owing to the decreased density and buoyancy of the hot air. The error at 110° C., the weight at room temperature being standard, is 0·02%, and in a comparison of results at temperatures ranging from 80° to 130°, the maximum error amounts to 0·01 per cent. The correction was therefore not applied in this work.

The above observations are typical of the best technical practice, and the results differ from those of the desiccator method in that (*a*) the sample is heated, (*b*) the drying is done with air which contains a certain amount of moisture. On account of (*a*) the sample loses material other than hygroscopic water at high temperatures. On account of (*b*) a certain amount of hygroscopic water is retained. The result is that the dry weight obtained by this method is greater than the true dry weight at moderate temperatures, and less at high temperatures.

3. *The Small Oven Method*—In this method the samples were placed in a small electrically heated oven (of the biological incubator type), which could be regulated to any desired temperature. This oven was not provided with a fan, but there was adequate provision for natural ventilation. The chief value of this method was that the true dry weight of the samples dried in it could be determined by the desiccator method (for which the samples dried in the commercial oven were too large). This method is also valuable in the study of the effects of prolonged drying.

4. *The Box Oven Method*—In this method use was made of a metal box provided with an air-tight lid and inlet and outlet tubes. Weighing bottles containing the samples were put in this box, and the box was placed inside

the commercial oven. A current of air was drawn through the box, adequate pre-heating being obtained by a length of lead pipe attached to the inlet. This air could, if necessary, be dried by means of three drying towers, containing respectively calcium chloride, concentrated sulphuric acid, and phosphorus pentoxide.

5. *The Bulb Method*—An investigation of the effect of temperatures ranging from 100° C. to over 200° on the weight of soda-boiled cotton was carried out by heating the cotton in an evacuated bulb attached to a Töpler pump. The bulb was provided with a tap so that when necessary the bulb could be filled with dry air, closed by means of the tap, detached, and weighed. The heating was effected electrically by placing the bulb inside a heater consisting of a copper cylinder, covered with asbestos paper, wound with nichrome wire, and lagged with asbestos cloth.

The Definiteness of the Commercial "Dry Weight"

If a commercial test were carried out as rigorously as an accurate laboratory experiment, it would be found that a sample of cotton continued to lose weight for a period of days or even weeks, and it would be impossible to obtain a constant in the few hours usually devoted to a test. In actual practice, however, the rate of loss soon becomes so slow that the criterion of "constancy" adopted allows an apparently constant weight to be obtained.

The acceptance of a "dry weight" that is not a constant weight thus depends upon the possibility of differentiating between the initial rapid loss and the subsequent slower loss. If the change is insufficiently sharp, the "dry weight" may depend to a large extent on the personal judgment of the person performing the test, and the results obtained by different persons may differ appreciably.

Numerous experiments have been made to test this point in different types of ovens, and a typical set of results, obtained with the electrically heated, commercial drying oven described above, is shown in Table I.

Table I

36's American Yarn, Grey, in Hank Form. Dried at 110° C. (230° F.)

Time	Weight	Regain at any stage: assuming dry weight equal to final weight	Initial regain assuming the weight at each stage to be the true dry weight
minutes	grams	%	%
0	555·89	6·44	—
34	523·46	0·23	6·19
59	522·57	0·06	6·38
88	522·49	0·05	6·39
130	522·44	0·04	6·40
174	522·44	0·04	6·40
252	522·39	0·03	6·41
311	522·35	0·02	6·42
360	522·29	0·01	6·43
402	522·30	0·01	6·43
443	522·29	0·01	6·43
553	522·29	0·01	6·43
608	522·25	0·00	6·44
660	522·26	0·00	6·44
705	522·25	0·00	6·44

In this experiment the drying process was extended over a period of nearly twelve hours, without any perfectly satisfactory indication of constancy.

In the later stages, however, the rate of loss was so small that successive weighings sometimes were the same. From a practical point of view the weight could have been regarded as constant after one hour. The fourth column of the table gives the values of the initial regain that would have been obtained if the drying had been stopped at any stage, and the weight at that stage taken as the true dry weight. It will be seen that over a considerable range the calculated regain does not differ appreciably from the value based on the final reading. The commercial "dry weight" is therefore a well-defined magnitude.

The differentiation of the initial rapid loss from the subsequent slow loss tends to become less sharp the higher the temperature of drying. At about 140° C. it is impossible to obtain anything corresponding to the commercial "dry weight" obtained at lower temperatures. This is illustrated by the time-weight graphs given in Fig. 1, which refer to a sample dried successively at a series of temperatures. This temperature of 140° is, of course, much higher than would be adopted in any commercial drying.

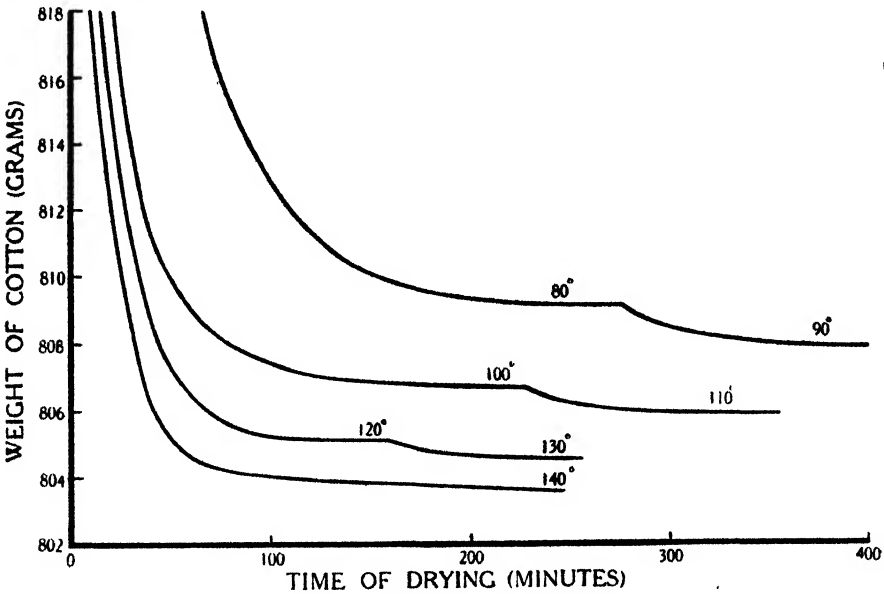

FIG. 1

Variation of the Commercial "Dry Weight" with the Temperature of Drying and with the Humidity of the External Atmosphere

It is well known that the apparent dry weight obtained in a commercial test depends upon the temperature of the oven. It is perhaps less well known that it depends also on the hygrometric state of the air outside the oven. To investigate the effect of these two factors dry weight determinations have been performed in the commercial form of drying oven.

Table II gives the results of experiments with raw and bleached cotton, both loose and in yarn form. The apparent dry weights have been determined over a range of temperatures, and under different atmospheric conditions. The procedure employed was to dry from 500–1,000 gm. of cotton at 80° C. until the weight was constant, the criterion of constancy adopted being that two weighings taken 15 minutes apart should not differ by 0·02 gm.; the temperature of the oven was then raised to 90° C. and the drying

Table II

The Apparent Dry Weight of Loose Cottons and Yarns at different Temperatures, with Calculated Residual Regains and Corrected Dry Weights

Temp. °C.	Weight	Part. Press. mm. Mercury	R.H. %	Residual Regain %	Corrected Weight
		Reference A—Grey Yarn. 36's American			
80	100·29	7·4	2·1	0·42	99·87
90	100·14	8·0	1·5	0·28	99·86
100	100·00	8·3	1·1	0·17	99·83
110	99·89	8·1	0·8	0·10	99·79
120	99·79	8·2	0·6	0·06	99·73
130	99·72	8·1	0·4	0·03	99·69
90	99·95	8·1	1·5	0·28	99·67
		Reference B—Grey Yarn. 36's American			
90	100·21	12·1	2·3	0·41	99·80
100	100·00	12·2	1·6	0·25	99·75
110	99·86	11·8	1·1	0·14	99·72
120	99·74	11·0	0·8	0·08	99·66
130	99·66	11·1	0·6	0·04	99·62
		Reference C—Loose Cotton. Sakel			
80	100·32	8·7	2·5	0·50	99·82
90	100·15	7·6	1·4	0·27	99·88
100	100·00	7·9	1·0	0·16	99·84
110	99·88	8·7	0·8	0·11	99·77
120	99·77	9·3	0·6	0·07	99·70
130	99·68	9·5	0·5	0·04	99·64
90	99·95	8·6	1·6	0·30	99·65
		Reference D—Loose Cotton. Sakel			
80	100·40	9·3	2·6	0·53	99·87
90	100·17	8·3	1·6	0·30	99·87
100	100·00	8·5	1·1	0·18	99·82
110	99·90	8·2	0·8	0·10	99·80
120	99·81	8·6	0·6	0·06	99·75
130	99·73	8·3	0·4	0·03	99·70
90	99·98	8·4	1·6	0·29	99·69
		Reference E—Bleached Yarn. 36's American			
80	100·23	6·9	1·9	0·39	99·84
90	100·09	7·1	1·4	0·25	99·84
100	100·00	7·3	1·0	0·15	99·85
110	99·94	8·2	0·8	0·10	99·84
120	99·90	8·3	0·6	0·06	99·84
130	99·86	7·6	0·4	0·03	99·83
90	100·07	8·0	1·5	0·28	99·80
		Reference F—Loose Cotton Bleached			
80	100·39	11·5	3·3	0·55	99·74
90	100·15	11·5	2·[illegible]	0·40	99·75
100	100·00	11·2	1·4	0·23	99·77
110	99·89	11·7	1·1	0·14	99·75
120	99·82	11·7	0·8	0·08	99·74
130	99·78	11·7	0·6	0·04	99·74
90	100·14	10·7	2·0	0·37	99·77
		Reference G—Loose Cotton. Bleached			
90	100·12	10·9	2·1	0·38	99·74
100	100·00	12·2	1·6	0·25	99·75
110	99·89	12·2	1·1	0·15	99·74
120	99·84	12·7	0·9	0·09	99·75
130	99·80	12·7	0·6	0·05	99·75
90	100·12	11·4	2·2	0·40	99·72

The apparent dry weights have been expressed as percentages of that at 100° C. Corresponding to each dry weight is given the partial pressure of water vapour in the room and the calculated value of the relative humidity in the oven. The last two columns of the table give the results of certain calculations referred to later in the paper.

continued at that temperature until the weight was again constant. In the same way, the cotton was successively dried at 100°, 110°, 120°, and 130° C., and after being allowed to cool and absorb moisture, again dried at 90° C.

One reason for the diminution of the apparent dry weight with rise of temperature is the diminution of the relative humidity of the air inside the oven, which causes a diminution of the amount of hygroscopic moisture in the cotton. This cannot, however, be a complete explanation, for it will be seen from the table that the variation with temperature of the apparent dry weight is very much greater for raw than for bleached cotton. If there were no other factor operative, this would imply that raw cotton was much more hygroscopic than bleached cotton; the results of Urquhart and Williams[7] however, show that the hygroscopicity of raw cotton is only slightly greater than that of bleached cotton. Moreover, if the apparent dry weights obtained in the two dryings at 90° C. are compared, it is seen that with raw cotton the second weight is considerably less than the first, whilst with bleached cotton the two are substantially the same. It follows, therefore, that part of the diminution of dry weight must be due to loss of material other than hygroscopic moisture, and that such loss is greater with raw than with bleached cotton, so that it is mainly due to the decomposition or evaporation of the non-cellulosic constituents.

It is of interest to observe that though the variation with temperature of the dry weight is much greater for raw than bleached cotton, the variation with humidity (expressed as partial pressure of water) at constant temperature is the same for both. This is evident from Table III. The column headed "Dry Conditions" gives the difference between the dry weights at 90° and 130° of Samples A and E. The column headed "Moist Conditions" gives the corresponding difference for Samples B and F. Since the low and the high partial pressures were respectively roughly equal for the raw and bleached samples, the differences between these two columns (given in the last column) will represent the increase in hygroscopic moisture due to the same increase of partial pressure. The two results (0·13% and 0·14%) are practically the same.

Table III

	Dry Conditions	Moist Conditions	Difference
Unbleached	0·42 (A)	0·55 (B)	0·13
Bleached	0·23 (E)	0·36 (F)	0·14
Difference	0·19	0·18	—

The amount of loss by decomposition or distillation can be measured directly by drying over phosphorus pentoxide at room temperature before and after the heat treatment. Such loss will cause a diminution of the "true dry weight." Table IV gives the results of experiments conducted in the small oven. Samples were dried at room temperature, heated at different temperatures, and finally dried again at room temperature.

Even after prolonged heating the bleached yarn loses only 0·05%, while the grey yarn loses 0·41%, and the conclusion may be drawn, therefore, that with bleached cotton the permanent loss by heating to 130° for the relatively short times required for the tests of Table II is negligible. Consequently, to obtain the residual regains of the bleached samples, all that requires to be

known are the small residual regains at 130° C. These may be obtained from the data of Urquhart and Williams[8]—

Temp.		Partial pressure		Regain
°C.		mm.		%
129·2	...	248	...	0·9
128·9	...	353	...	1·3

The small temperature differences being neglected, the regain at this high temperature is proportional to the partial pressure, the factor of proportionality being 0·0037. The regain at lower partial pressures is thus readily calculated, and for the partial pressures occurring in Table IV ranges from 0·03% to 0·05%.

Table IV

True Dry Weight = 100

Temp. °C.	Partial Pressure of Vapour (mm.)	R.H. % in Oven	Grey Yarn		Bleached Yarn	
			Time of Heating hrs.	Weight	Time of Heating hrs.	Weight
80	12·8	3·6	109	100·73	90	100·67
90	10·5	3·1	51	100·44	54	100·43
100	12·1	1·6	36	100·17	38	100·24
110	11·8	1·1	122	99·98	129	100·17
120	11·0	0·75	83	99·79	87	100·05
130	12·4	0·6	36	99·66	98	100·02
Room temp.	—	—	—	99·59	—	99·95

It is thus possible to calculate the regains of the dried bleached yarns. These regains are shown plotted against the partial pressures in Fig. 2. It will be noticed that the graphs are approximately straight lines, indicating that the regain is proportional to the partial pressure, so that the absorption obeys Henry's Law. The coefficients of proportionality are given in Table V.

Table V

Desorption at High Temperatures and Low Humidities

Temperature °C.				Coefficient (regain/partial pressure)
80	...	...	...	0·0571
90	...	...	...	0·0349
100	...	...	...	0·0208
110	...	...	...	0·0121
120	...	...	...	0·0070
130	...	...	...	0·0037

These values, or the graphs of Fig. 2, may be used to calculate the residual regain of cotton dried at high temperatures. They apply strictly only to bleached cotton, but they may be used without serious error for raw cotton.

The last column of Table II gives the result of deducting from each apparent dry weight the regain as calculated from the coefficients of Table V. For the bleached samples the resultant "corrected dry weights" do not vary appreciably with the temperature, such small variations as occur being accidental and corresponding to the random deviations of the points from the graphs (Fig. 2). For the unbleached samples the corrected dry weights diminish with the temperature of drying. This is due to the loss of material other than hygroscopic water. The corrected dry weight does not appear to diminish till a temperature of 100° is reached, so that at 80° and 90° it is equal to the true dry weight. The values of the permanent loss at the

higher temperatures, calculated by subtracting from the corrected dry weights the mean of the corrected dry weights at 80° and 90°, are given in Table VI. The value of the permanent loss at 130° is less than that given in Table IV, owing to the shorter time of heating.

Table VI

The Permanent Loss of Unbleached Samples

Temp. °C.	% Loss*				
	A	B	C	D	Mean
100	0·04	0·05	0·01	0·05	0·04
110	0·08	0·08	0·08	0·07	0·08
120	0·14	0·14	0·15	0·12	0·14
130	0·18	0·18	0·21	0·17	0·19

* As calculated (by simple subtraction), these values are percentages reckoned on the uncorrected dry weight at 100°; they do not differ appreciably from those reckoned on the true dry weight.

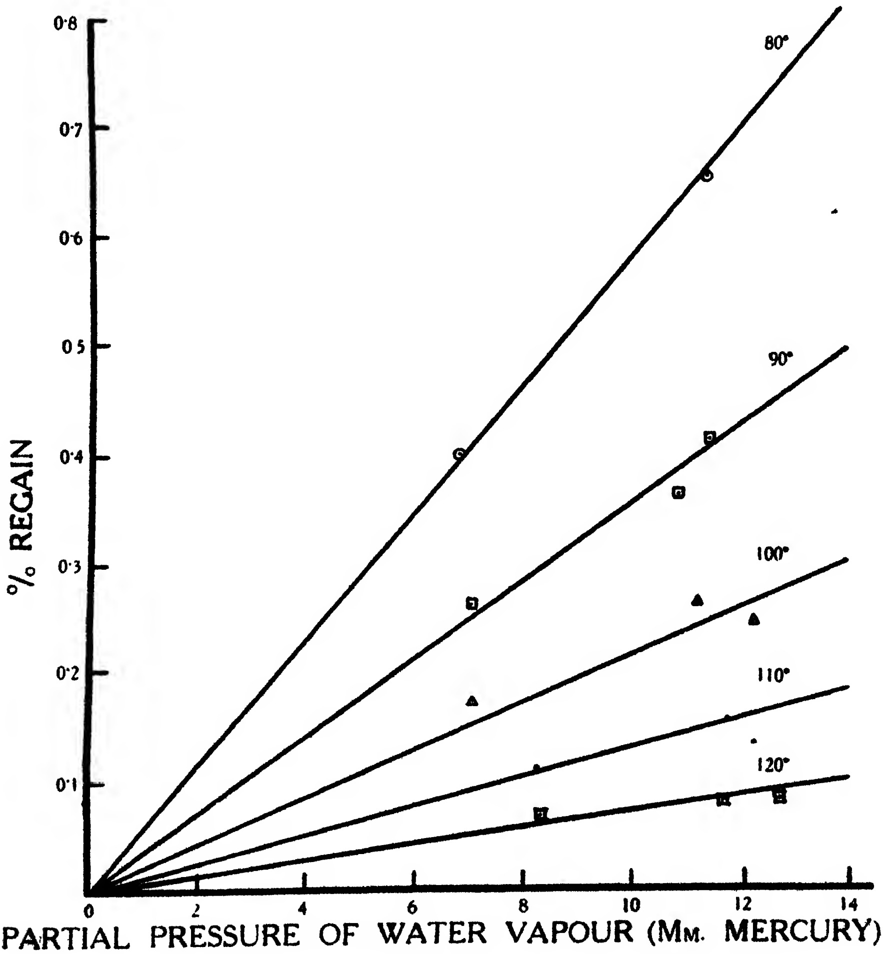

FIG. 2

Hysteresis at High Temperatures and Low Humidities

The question of progressive permanent loss of weight on drying cotton at temperatures above 100° C. was also investigated by allowing cotton which had been dried at 80°, 90°, 100°, 110°, 120°, and 130° C. to pick up moisture and drying it again at 90°. On comparing the two weights obtained at 90° it was found that whilst with bleached yarn there was practically no difference in the two weights, with grey yarn they differed by amounts in very close agreement with those calculated and shown in Table VI. If, however, instead of allowing the yarn to cool to room temperature and absorb moisture before re-drying, it was taken straight from 130° to 90° C. by lowering the temperature of the oven, it was found that even the bleached yarn showed a significant difference between the two weights at 90° C., while the difference with grey yarn was increased. This was evidently due to hysteresis, which is well known to occur at ordinary temperatures and relative humidities.

In the experiments that were carried out to elucidate this question, the cotton was first dried at 90° C. (desorption), then at 130° C., and then, without removing the cotton from the oven, the temperature was reduced to 90° C. and maintained until the weight was again constant (absorption). After being allowed to stand overnight, the cotton was again dried at 90° C. (desorption). Typical results obtained are given in Table VII.

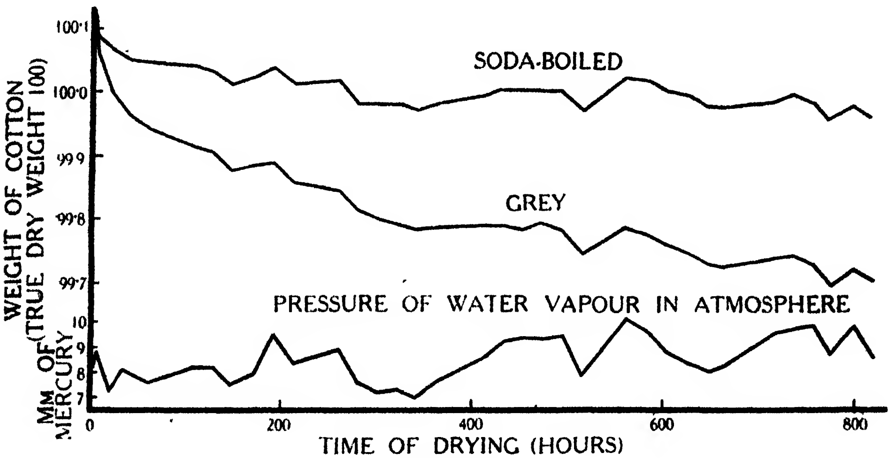

Fig. 3

Table VII

Cotton	Temp. °C.	Drying Process	Weight	Vapour Pressure (mm. Mercury)	Residual Regain (calc.)	Corrected Weight	Hyster-esis
American Bleached Yarn	90	Desorption	100·00	10·1	0·36	99·64	—
	130	—	99·65	10·4	·04	99·61	—
	90	Absorption	99·91	10·9	·38	99·53	}·07
	90	Desorption	99·98	10·9	·38	99·60	
American Grey Yarn	90	Desorption	100·00	11·2	0·40	99·60	—
	130	—	99·52	11·9	·04	99·48	—
	90	Absorption	99·79	11·5	·41	99·38	}·11
	—	Desorption	99·88	11·0	·39	99·49	

The mean of the two values of the hysteresis at 90° C. is 0.09 per cent. Urquhart and Williams[8] found that as the temperature increases the hysteresis loop becomes smaller, and concluded that hysteresis would be negligible in the neighbourhood of 100° C. However, the above results show that it is still appreciable at 2% R.H. at 90° C., although too small to be measured by the method employed by Urquhart and Williams.

Experiments with Small Samples

As a check on the experiments with large samples in the commercial oven, observations have been made on the dry weight of small samples (weighing a few grams) in drying bottles. These were first dried over phosphorus pentoxide, so as to obtain the true dry weight. The samples were then dried in the box oven or in the small oven. In order to render the results comparable with those for the large samples, these small samples were heated for four hours at each temperature. In the box oven one sample was dried in a current of ordinary air, and another in a current of dried air. In the small oven a grey and a bleached sample were dried in ordinary air. The results are shown in Table VIII (overleaf).

The general validity of Table V for calculating the residual regain is most simply verified by working out, from the observed partial pressures and the coefficients of Table V what the apparent dry weights of the samples should be at 80° and 90°, and comparing them with the observed values. At these temperatures the permanent loss is negligible. The comparison is shown in Table IX (overleaf).

At the higher temperatures the corrected dry weights of the raw cotton are less than the true dry weight, the difference being the permanent loss. Table X (overleaf) shows that the values of the permanent loss do not differ much from those of the large samples.

The permanent loss that occurs during short period drying at high temperatures is simply the initial more rapid portion of a process which continues for a long time, and it may be small if the sample is subjected to the higher temperatures for only a short time. Thus the grey yarn of Table VII shows a permanent loss of only 0·11%, owing to the shortness of the time of exposure to a higher temperature.

The residual regain of cotton dried in a current of air under various conditions of temperature and moisture content has been estimated by Obermiller and Goertz.[5] As is evident from Table XI, their estimates are appreciably higher than those of the present paper.

Table XI

The Results of Obermiller and Goertz

Temp. of Drying, °C.	R.H. (%) of Air at 21° C.	Partial Pressure mm. Mercury	Residual Regain %	Residual Regain(%) from Results of present Paper
75–80	75	14·0	1·05	0·82
	35	6·4	0·55	0·35
95–100	100	18·6	0·65	0·44
	75	14·0	0·55	0·33
	55	10·2	0·40	0·24
	35	6·4	0·25	0·15
	2·5	0·5	0·06	0·01
105–110	75	14·0	0·35	0·19

Table VIII

Experiments with Small Samples of 36's American Yarn

True dry weight = 100

Temp. °C.	Box Oven						Small Oven							
	H (grey)				J (grey)		K (grey)				L (bleached)			
	Dry Weight	Part. Press. mm.	Regain % (calc.)	Corrected Dry Weight	Dry Weight	Part. Press. mm.	Dry Weight	Part Press. mm	Regain % (calc.)	Corrected Dry Weight	Dry Weight	Part. Press. mm.	Regain % (calc.)	Corrected Dry Weight
80	100·41	6·8	0·39	100·02	100·00	—	—	—	—	—	—	—	—	—
90	100·27	6·9	0·24	100·03	99·97	—	100·31	8·7	0·31	100·00	100·28	8·7	0·31	99·97
100	100·10	7·8	0·17	99·93	99·92	—	100·16	8·8	0·18	99·98	100·16	8·8	0·19	99·97
110	99·97	8·5	0·10	99·87	99·89	—	100·05	9·8	0·12	99·93	100·09	9·8	0·12	99·96
120	99·92	9·2	0·07	99·85	99·83	—	99·95	8·5	0·06	99·89	100·03	8·5	0·06	99·97
130	99·86	7·6	0·03	99·83	99·80	—	99·87	7·2	0·02	99·85	100·00	7·2	0·02	99·98

Table IX

Sample	Temperature	Dry Weight	
		Calculated	Actual
H	80° C.	100·39	100·41
H	90° C.	100·24	100·27
K	90° C.	100·31	100·31
L	90° C.	100·31	100·28

Table X

Permanent Loss (%) of Small Samples

Temp. °C.	H	J	K	Mean	Mean for Large Samples
100	0·07	0·08	0·02	0·06	0·04
110	0·13	0·11	0·07	0·08	0·08
120	0·15	0·17	0·11	0·14	0·14
130	0·17	0·20	0·15	0·17	0·19

Obermiller and Goertz[5] quote a result obtained by Renker with sulphite pulp. Drying at 98° C. with air saturated at 24°–25° C., Renker found a residual regain of 0·64%, which is in good agreement with the value (0·59) deduced from the results of the present paper, but appreciably different from that deduced from the data of Table XI (0·86).

The Prolonged Drying of Cotton

The variation of the weight of raw and bleached cotton on being heated for a long period has been investigated by placing samples (contained in weighing bottles) in the small electric oven. The experiments were performed at 100° C. and at 110° C. The samples were dried over phosphorus pentoxide previous to heating. At first weighings were made every few hours, but later they were made daily; records of the hygrometric state of the atmosphere were kept during the course of the experiments. The results at 110° C. (Fig. 3) show that the slow loss of the raw samples is greater and proceeds for a longer time than that of the bleached samples. In both cases there are fluctuations of weight corresponding to the changes in the partial pressure of the water vapour in the external atmosphere. The progressive diminution of weight of the bleached cotton ceases after about 300 hours, the subsequent changes being merely fluctuations in response to atmospheric humidity variations. The weight of raw cotton, on the other hand, does not become steady even after 800 hours, though the rate of loss is so small that the response to atmosphere humidity is quite evident.

The Permanent Loss of Soda-boiled Cotton

Although the permanent loss of bleached cotton is not serious at the temperatures ordinarily used for drying, it is of interest to study the effect at higher temperatures. This has been done with soda-boiled sliver. The material was dried to constant weight at room temperature in a vacuum of about 0·001 mm. of mercury, the moisture being absorbed by a phosphorus pentoxide tube between the bulb containing the cotton and the pump. The bulb was then heated successively to various temperatures (three hours at each temperature), the vacuum being maintained. The results are given in Table XII, the weight at each temperature being expressed as a percentage of that at room temperature. The weight of the sample was about 14 gm. and the balance used was capable of weighing to the nearest 0·001 gm., so that the estimate of the loss at 100° C. (0·03%) is not very accurate.

Table XII

Loss of Weight of Soda-boiled Cotton on Heating for Three Hours at various Temperatures in vacuo

Temp. °C. ...	15	100	135	15	160	182	200	15	212
Weight ...	100·00	99·97	99·93	99·93*	99·89	99·81	99·69	99·70*	99·59

* These weights were obtained by allowing the cotton to absorb moisture and then drying again at 15° C.

The values of the loss at 100° and 135° are somewhat larger than would be expected from the results of the previous experiments with the commercial oven. This is probably due partly to errors in weighing the small samples used, and partly to increased loss by volatilisation, owing to the reduced pressure. A deposit of waxy matter was noted in the upper, cooler, part of the bulb. This would, of course, be included in the weight, but it is reasonable to suppose that it does not represent all the material evaporated.

Nelson and Hulett[4] have measured the amount of moisture given off by absorbent cotton when heated in vacuo to temperatures of 115° C. to 238° C. Their results are given as percentages of moisture in the original cotton, but for purposes of comparison with those in Table XII they have been reduced to the same basis as the latter, the relative weight at 115° C. being taken as the same for both. These reduced results are given in Table XIII and compared with the present data. The agreement is good, in view of differences in material and technique.

Table XIII

Temp. °C.	Time of Heating (hours)	% Moisture	Relative Weight of Cotton	
			From Data of N. & H.	From Data of Table XII
115	2	5·49	(99·96)	(99·96)
132	3	5·55	99·88	99·94
155	3	5·57	99·87	99·90
184	5	5·63	99·81	99·80
218	3	5·74	99·69	99·54
238	2⅜	6·11	99·30	99·32

Nelson and Hulett, however, attribute the progressive loss of weight to loss of moisture by desorption. They believe that the adsorbed water is not completely removed by drying over phosphorus pentoxide at room temperature, but is progressively removed as the temperature is raised. Now if this were so, the process should be reversible, and if after drying at a high temperature the cotton were allowed to pick up moisture, and were again dried at room temperature, it should revert to its original dry weight at room temperature. Nelson and Hulett did not test this point. In the present work the cotton was allowed to regain moisture, and was again dried at room temperature at two stages, after heating to 135° and to 200°. The values of the dry weights thus obtained have been inserted in Table XII at the appropriate places. It will be seen that the diminution of dry weight is permanent, and, in so far as it is due to loss of water, must be attributed to the loss of water more intimately related to the cotton than adsorbed water.

Some of the experimental work was done by Mr. F. G. Wilde.

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10—SHRINKAGE AND TAKE-UP OF YARN IN KNITTED FABRICS

By W. E. Boswell, F.T.I.

The term "shrinkage" in the following report refers to the contraction that takes place in a row of knitted loops from the time that they leave the needles of a knitting machine to the time when the fabric has been removed from the machine and allowed to "settle." The first measurement is taken as the loops hang from the needles, the second being obtained from the fabric laid out on a flat surface.

Shrinkage often takes place during the finishing, i.e. scouring, dyeing, and pressing of the fabric; this shrinkage is not dealt with here.

The term "take-up" refers to the amount of yarn required to make a given length of loops in a knitted fabric; a take-up of three indicating that three inches of yarn would be used to make one inch of loops. Weft knitted fabrics only are dealt with and the loops are measured along the course or across the width of the fabric.

SHRINKAGE MEASUREMENTS

Knitted fabrics contract in width as they leave the needles of the frame, the amount of contraction varying according to the length of loop, nature and count of yarn, gauge of machine, and type of fabric made. The following tables give the results of experiments made on various types of knitting machines. The yarns used are shown in column 2, the total width of needles in column 4, and the width of the fabric when it had been allowed to lie for several hours is given in the 5th column.

The percentage shinkage is calculated as follows—Test No. 1; width of needles, 66 inches; width of fabric, 51·1 inches; $66 - 51{\cdot}1 = 14{\cdot}9$ inches shrinkage in 66 inches, or $\frac{14{\cdot}9 \times 100}{66} = 22{\cdot}5$ per cent These results are shown in the last column of the table.

Table I

Latch Needle Circular Web Machine (without Sinkers)

Test No.	Yarn	Needles per inch in Machine	Circumference of Needle Cylinder	Single Width of Fabric	Percentage Shrinkage
1	2/10's worsted	6·96	66	51·1	22·5
2	2/15's ,,	6·97	62·8	41·8	33·4
3	8's cotton	11·95	59·7	44·8	25·3
4	450 den. art. silk	11·95	59·7	47·6	20·2
5	2/30's mer. cotton	15·92	56·5	40·9	27·6
6	24's worsted	15·92	56·5	37·5	33·6
7	26's ,,	15·92	56·5	37·5	33·6
8	490 den. art. silk	16	62·8	50·3	19·9
9	2/48's worsted	16·1	59·7	46·0	22·9

Normal counts of yarn were used in tests 1, 3, 4, 5, and 9. The yarns used for experiments 2, 6, and 7 were rather light, while that used in number 8 was heavy for the gauge of the machine. Where normal counts of yarn were used

an average of 23·7% shrinkage was obtained. Tests 2, 6, and 7 show that the shrinkage increases with the finer counts of yarn, while No. 8, where the yarn was heavy for the gauge, shows less shrinkage than any other.

Table II

Latch Needle Circular Web Machines (with Sinkers)

Test No.	Yarn	Needles per inch in Machine	Circumference of Needle Cylinder in.	Single Width of Fabric in.	Percentage Shrinkage
1	8's cotton	10	88	56·6	35·6
2	2/24's worsted	10	88	58·6	31·1
3	2/28's ,,	10	88	51·8	41·1
4	500 den. art. silk	10	88	55·0	37·5
5	2/24's worsted	12	66	44·0	33·3
6	2/48's ,,	16·05	81·7	59·6	27·05

The yarns used in these experiments were correct for the gauge; No. 3, which shows the most shrinkage, being the only one that would be considered light for the set of the needles. It is noticed that the shrinkage on this type of machine is greater than on the non-sinker type, the average being (leaving out No. 3) 32·9 per cent.

Table III

Latch Needle Seamless Hose Machines

Yarn	Needles per inch in Machine	Circumference of Needle Cylinder in.	Single Width of Fabric in.	Percentage Shrinkage	Part of Hose
2/8's cotton	6·7	12·5	8·2	34·4	leg
2/32's worsted	12·3	9·4	6·2	34·04	,,
2/32's ,,	13·37	12·5	8·8	29·6	,,
16's cotton	16·1	11·78	9·5	19·4	top
300 den. art. silk	16·1	11·78	8·2	30·3	leg
,, ,, ,,	16·1	11·78	7·5	36·3	ankle
2/40's merc. cotton	16·9	11·78	9·8	16·9	top
250 den. art. silk	16·9	11·78	9·0	23·6	leg
,, ,, ,,	16·9	11·78	8·0	32·0	ankle
20's cotton	18·64	11·78	9·0	23·6	top
150 den. art. silk	18·64	11·78	7·8	33·7	leg
,, ,, ,,	18·64	11·78	7·0	40·5	ankle
2/50's merc. cotton	21·8	11·0	9·6	12·7	top
120 den. art. silk	21·8	11·0	8·4	23·6	leg
,, ,, ,,	21·8	11·0	7·0	36·3	ankle

Table IV

Bearded Needle Hose Machines

Yarn	Needles per inch in Machine	Circumference of Needle Cylinder in.	Single Width of Fabric in.	Percentage Shrinkage	Part of Hose
2/50's merc. cotton	22·03	11·78	10·6	9·4	top
120 den. art. silk	22·03	11·78	9·8	17·1	leg
,, ,, ,,	22·03	11·78	7·6	35·04	ankle

The stitch length is automatically varied during the manufacture of seamless hose; the top of the leg being made in a slack stitch to give a wide top, the stitch length being gradually shortened from the calf to the ankle. The above tables show how this affects the width of the fabric and gives shape to the stocking.

Table V

Bearded Needle Circular Web Machines

Test	Yarn	Needles per inch in Machine	Circumference of Needle Cylinder in.	Single Width of Fabric in.	Percentage Shrinkage
1	2/50's worsted	18	34	30·6	10·0
2	2/36's cotton	18	34	29·4	13·5
3	2/54's worsted	18	34	29·1	14·4
4	300 den. art. silk	18	34	27·8	18·2
5	,, ,, ,,	19	83·3	79·2	4·9
6	20's cotton	21	52·5	44·0	16·1

These experiments show that bearded needle circular machines give a wider fabric for a given width of needles than is obtained on latch needle machines. The average of the tests made is 12·4%, all the yarns being of suitable size for the machines. Tests 1, 2, 3, and 4 illustrate the variation in the shrinkage due to the changing of the yarn, the courses per inch being 20, 20, 21, and 22 respectively.

Table VI

Straight-Bar Bearded Needle Frames

Test	Yarn	Needles per inch in Frame	Width of Needles in.	Width of Fabric in.	Percentage Shrinkage
1	8's cotton	14	20	16·8	16
2	2/24's worsted	14	20	16·0	20
3	600 den. art. silk	14	10	8·4	16
4	2/22's worsted	16	10	8·8	12
5	18's ,,	20	10	9·0	10
6	24's ,,	22	10	8·1	19
7	2/60's cotton	26	10	8·3	17
8	2/64's ,,	28	10	8·5	15

Tests 1 and 2 were made with similar conditions of tension on the yarn and show that the fabric made with the worsted yarn shrunk 4% more than that made with a cotton yarn of equivalent count.

Table VII

Latch Needle Circular Rib Machines

Test	Yarn	Needles per inch in Machine	Circumference of Needle Cylinder in.	Single Width of Fabric in.	Percentage Shrinkage
1	2/18's worsted	8·98	13·3	4·7	64·6
2	8's cotton	12·3	9·3	3·6	61·2
3	2/32's worsted	13·3	12·5	5·0	60·0
4	16's cotton	19·6	44·0	27·0	38·6

The few tests made on rib machines show that the shrinkage is much greater in rib than in plain fabrics. This is due to the different intersections of the yarn as shown in Figs. 1 and 2.

The shrinkage in the fabrics made on the small diameter machines (tests 1, 2, and 3) is greater than in that made on the wider machine.

SUMMARY OF RESULTS

The bearded needle machines, both circular and straight bar, employ loop forming sinkers which form loops over the shanks of the needles; on all the other types dealt with the loops are formed by the needles drawing the yarn through the old loop and over the needle groove walls or the noses of the sinkers.

It is noticed that the machines using loop-forming sinkers produce a wider fabric for a given width of needles than is produced on other types. Yarns that are heavy for the set of the needles give a fuller fabric and restrict the shrinkage; light counts of yarn allow the fabric to shrink more than would be the case if normal counts were used.

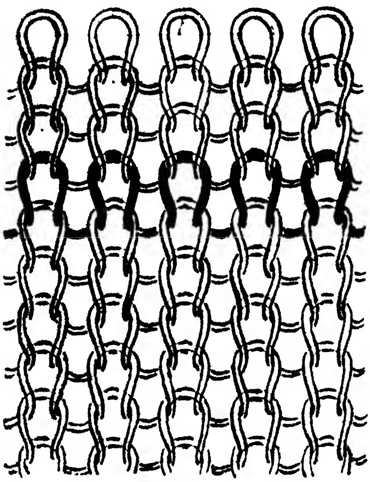

FIG. 1 Plain Fabric

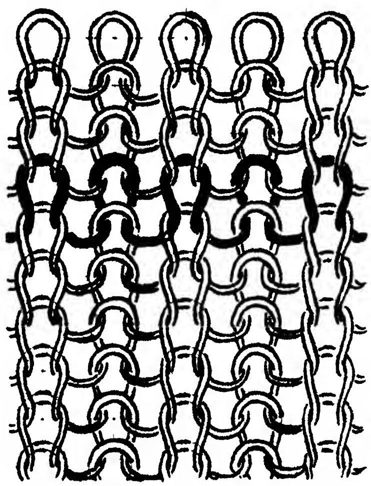

FIG. 2 1 and 1 Rib Fabric

APPLICATION OF RESULTS

It is often necessary to estimate the amount of shrinkage that has taken place in a sample of fabric in order to arrive at the approximate gauge of the machine on which a fabric of similar texture could be made. For example, a fabric with 15 stitches per inch may be assumed to have shrunk 20% from the needles of the frame. The following calculation would give the approximate set of the needles on which the fabric was made—

$$100 - 20 = 80, \frac{15 \times 80}{100} = 12 \text{ needles per inch in the frame.}$$

Similarly when a fabric of a certain width is required, an allowance must be made for shrinkage from the needle width as follows—

If the fabric is required 20 inches wide off the frame and the shrinkage from the needles is 18%, the width of needles required will be—

$$100 - 18 = 82;$$

$$\frac{20 \times 100}{82} = 24{\cdot}4 \text{ inches.}$$

TAKE-UP OF YARN

The take-up of yarn in a knitted fabric may be determined by working a marked and measured length of yarn on the machine, the number of loops formed by this length being counted and converted to inches by dividing by needles per inch in the machine. The number of inches of yarn used, divided by the inches of loops made, will give the take-up of the yarn during loop formation.

The following tables give the take-up of yarn on various types of knitting machines, the shrinkage of the fabric with the resultant take-up of yarn in the fabric also being given.

The length of yarn marked for the test is shown in the column A, the length of loops made with that length being shown at B (the measurement being taken on the needle line), and $\frac{A}{B}$ gives the take-up of the yarn during loop formation.

The take-up of the yarn in the fabric will be greater than on the needles, as the fabric contracts as it leaves the machine, giving more loops to the inch. Taking Test No. 1 in Table I as an example, the take-up in the fabric is found as follows— $100 - 30{\cdot}8 = 69{\cdot}2$; $\frac{2{\cdot}44 \times 100}{69{\cdot}2} = 3{\cdot}52$; as fabric take-up where the take-up on the needles is 2·44 and the shrinkage from the needles is 30·8 per cent.

Table I
Latch Needle Circular Web Machines (without Sinkers)

Test	Yarn	Needles per inch in Machine	A (inches of Yarn)	B (inches of Loops)	A/B (Take-up)	Shrinkage %	Take-up in Fabric
1	3/16's worsted ...	5·53	12	4·9	2·44	30·8	3·52
2	450 den. rayon...	11·95	12	4·33	2·77	20·2	3·47
3	8's cotton ...	11·95	12	4·58	2·62	23·8	3·43
4	8's ,, ...	11·95	12	4·50	2·66	25·3	3·56
5	8's ,, ...	11·95	12	4·41	2·72	29·5	3·77

Tests 2 and 4 were made under similar conditions of tension, and it is noticeable that the artificial silk yarn has a greater take-up on the needles than the cotton yarn, the take-up in the fabric, however, being less. The length of the stitch was altered for Tests 3 and 5, No. 3 being made with a shorter stitch than No. 4, the last experiment being made with a lengthened switch, the courses per inch being 18½, 19, and 19½ respectively.

Table II
Latch Needle Circular Web Machines (with Sinkers)

Test	Yarn	Needles per inch in Machine	A (inches of Yarn)	B (inches of Loops)	A/B (Take-up)	Shrinkage %	Take-up in Fabric
1	8's cotton ...	10	12	5·5	2·18	28·6	3·05
2	8's ,, ...	10	12	5·3	2·26	29·9	3·21
3	8's ,, ...	10	12	5·2	2·30	35·6	3·57

Three qualities of fabric were made in these tests, the courses per inch being 14, 14½, and 15 respectively in Tests 1, 2, and 3.

Table III

Latch Needle Seamless Hose Machines

Yarn	Needles per inch in Machine	A (inches of Yarn)	B (inches of Loops)	A — B (Take-up)	Part of Hose	Shrinkage %	Take-up in Fabric
2/8's cotton ...	6·7	28½	12·5	2·28	leg	34·4	3·39
2/32's worsted ...	12·3	22¾	9·4	2·42	,,	34·04	3·70
8's cotton ...	12·3	24½	9·4	2·60	,,	27·7	3·59
2/32's worsted ...	13·37	34	12·57	2·70	,,	29·6	3·80
16's cotton ...	16·1	32½	11·8	2·75	top	19·4	3·41
300 den. rayon ...	16·1	29½	11·8	2·50	leg	30·3	3·58
,, ,, ...	16·1	26	11·8	2·20	ankle	36·3	3·45
2/40's mercerised cotton ...	16·9	29½	11·8	2·50	top	16·9	3·0
250 den. rayon ...	16·9	31	11·8	2·62	leg	23·6	3·42
,, ,, ...	16·9	28½	11·8	2·41	ankle	32·0	3·54
20's cotton ...	18·6	34½	11·8	2·92	top	23·6	3·82
150 den. rayon ...	18·6	32	11·8	2·71	leg	33·7	4·07
,, ,, ...	18·6	27	11·8	2·28	ankle	40·5	3·83
2/50's mercerised cotton ...	21·8	36½	11·0	3·31	top	12·7	3·79
120 den. rayon ...	21·8	32	11·0	2·90	leg	23·6	3·79
,, ,, ...	21·8	29	11·0	2·63	ankle	36·3	4·12

In these experiments the yarn was marked at intervals of one inch and the length of yarn taken to make a complete circle of loops was noted. This is shown in column A, the circumference of the needle cylinder being shown at B. Results show that the take-up decreases as the loop is shortened for the ankle of the stocking, but the shrinkage increases as the fabric is tightened so that the take-up of yarn in the fabric is actually greater in the ankle than in the top of the leg.

Table IV

Bearded Needle Circular Web Machine

Test	Yarn	Needles per inch in Machine	A (inches of Yarn)	B (inches of Loops)	A — B (Take-up)	Shrinkage %	Take-up in Fabric
1	8's cotton ...	11·9	12	5·04	2·38	25·3	3·18
2	300 den. rayon...	19	12	4·2	2·85	4·9	2·99
3	20's cotton ...	21	12	3·52	3·40	16·1	4·05
4	2/36's ,, ...	18	12	4·20	2·85	13·5	3·29

Test No. 1 in this table was made on the loop wheel frame, the remainder on the terrot type.

Table V

Straight-Bar Bearded Needle Frames

Yarn	Needles per inch in Frame	A (inches of Yarn)	B (inches of Loops)	A — B (Take-up)	Shrinkage %	Take-up in Fabric
2/24's worsted ...	14	12	3·78	3·12	16·0	3·71
8's cotton	14	12	3·78	3·12	16·8	3·87
600 den. rayon ...	14	12	3·64	3·27	8·4	3·56

These three experiments were made with the same amount of tension on the yarn and without any alteration of the stitch length.

Table VI

Latch Needle Circular Rib Machines (1 and 1 Rib Fabrics)

Yarn	Needles per inch in Machine	A (inches of Yarn)	B (inches of Loops)	A/B (Take-up)	Shrinkage %	Take-up in Fabric
2/18's worsted ...	8·98	33	13·35	2·47	64·4	6·97
8's cotton	12·3	25¾	9·40	2·73	61·2	7·03
2/32's worsted ...	13·37	32	12·57	2·54	60·0	6·35
16's cotton ...	19·6	12	3·46	3·47	38·6	5·65

The last of the above tests was made on a 14-inch diameter machine, the others on small machines used for the half-hose trade.

The take-up during knitting on the former was much greater than on the remainder, but the shrinkage was much less, so that the difference in the fabric take-up is not so marked.

SUMMARY OF RESULTS

The take-up of yarn during knitting varies between 2·18 and 3·4, bearded needle machines taking up more yarn per inch of loops than machines with latch needles. The take-up in the fabric varies between 2·99 and 4·12.

APPLICATION OF RESULTS

The amount of take-up during knitting is required to be known for calculations relating to the weight of yarn necessary to make a given length of fabric. The width of needles used multiplied by the take-up of yarn will give the length of yarn used to make one complete row of loops. The number of rows per inch can readily be determined by measurement when a sample of fabric has been made. The weight of yarn required for any length of fabric may then be determined by the following method—

Let W = width of needles in inches,
T = take-up of yarn during knitting,
C = courses of loops per inch, and
and L = length of fabric in yards.

$W \times T$ = inches of yarn in one course of loops,
$W \times T \times C$ = ,, ,, one inch of fabric,
$W \times T \times C \times 36$ = ,, ,, one yard of fabric,
$W \times T \times C \times 36 \times L$ = ,, ,, L yards of fabric,

$$\frac{W \times T \times C \times 36 \times L}{36} = \text{yards} \quad ,, \quad ,, \quad ,, \quad ,,$$

$$\frac{W \times T \times C \times 36 \times L}{36 \times \text{count} \times \text{basis}} = \text{lbs.} \quad ,, \quad ,, \quad ,, \quad ,,$$

Example—Calculate the weight of 1,000 yards of fabric made on 88 inches of needles, 8's cotton count, take-up of 2·18, 24 courses per inch.

$$\frac{88 \times 2{\cdot}18 \times 24 \times 36 \times 1{,}000}{36 \times 8 \times 840} = 685{\cdot}1 \text{ lbs.}$$

11—THE INFLUENCE OF HUMIDITY ON THE ELASTIC PROPERTIES OF COTTON

PART V—THE TENSILE BEHAVIOUR

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INTRODUCTION AND SUMMARY

The resistance of a single cotton hair to extension is the ultimate factor in the tensile behaviour of all cotton textiles, and is also of interest in the study of hair structure. Some experiments on the effect of humidity on the breaking load have already been described[5], but the more complete specification of the tensile behaviour given by measurements of ultimate extension and of resistance to extension up to the breaking point demands more elaborate apparatus and laborious observation. Barratt[1] described a "Fibre Balance." that serves the purpose, but from the present point of view his recorded observations on cotton serve only as illustrations of the methods. The problems now discussed demand more extensive and statistical data such as those given in this paper.

The apparatus employed was a modification of Barratt's, made from an accurate analytical balance with short arms. Near its axis, a fixed and a moving mirror were added, which, by multiple reflection of a beam of light on a scale, produced an eighty-fold magnification of the extension of the specimen. This was fastened in a special grip on one arm, the other being loaded by an O'Neill float, which was found both simpler and more efficient than the electro-magnetic device used by Barratt. This balance was enclosed in a humidity control box[5] and the hairs were sampled, mounted, and conditioned by the methods also described in the paper quoted. The efflux from the O'Neill cylinder was arranged to give any desired rate of loading and to be stopped and started by one observer, who also watched the spot of light that indicated on the scale the extension of the specimen.

In observing a complete curve of extension against load, a metronome was set to ring every two seconds, when the position of the spot of light was noted. A snap reading was taken at break and the amount of water run out was the measure of the breaking load. Sets of 50 load-extension curves were observed on Sakel and Texas hairs, tested under dry, moderate, and wet conditions. These are merely used to define the shape of such curves, for the effect of humidity on the end-point, the breaking load, and the extension, is not defined with sufficient precision by this number of tests. Other series were carried out on Sakel cotton, because of its convenient length and regularity, the end-point alone being observed on a total of 2,000 hairs at various humidities.

The influence of humidity on the breaking load and extension is shown by the curves of Fig. 1. The effect on the breaking load agrees with that found in the previous work; below 50% R.H. it is considerable and fully accounts for the increase in the strength of yarns, whilst above 60% R.H. there is no appreciable change, so that the varying sensitivity of the strength of yarns to humidity in this region must be ascribed to other factors.

The extension at break is affected in the same way as that of yarns. The change between 60% R.H. and 70% R.H. is 7·1% of the value at 70% R.H., which is identical with the figure previously given for yarns. Similarly, the slope decreases towards saturation, and indeed the ordinates in Fig. 5 of a previous paper[6] illustrating the extension of unsized yarn maintain a virtually constant ratio of 0·75 to those of Fig. 1 for hairs. Since the hairs in a yarn are fully extended only at the actual breaking place, little of the effect on yarn extension is left to be explained by structural factors, such as the straightening or slipping of the hairs. The more quantitative analysis of the

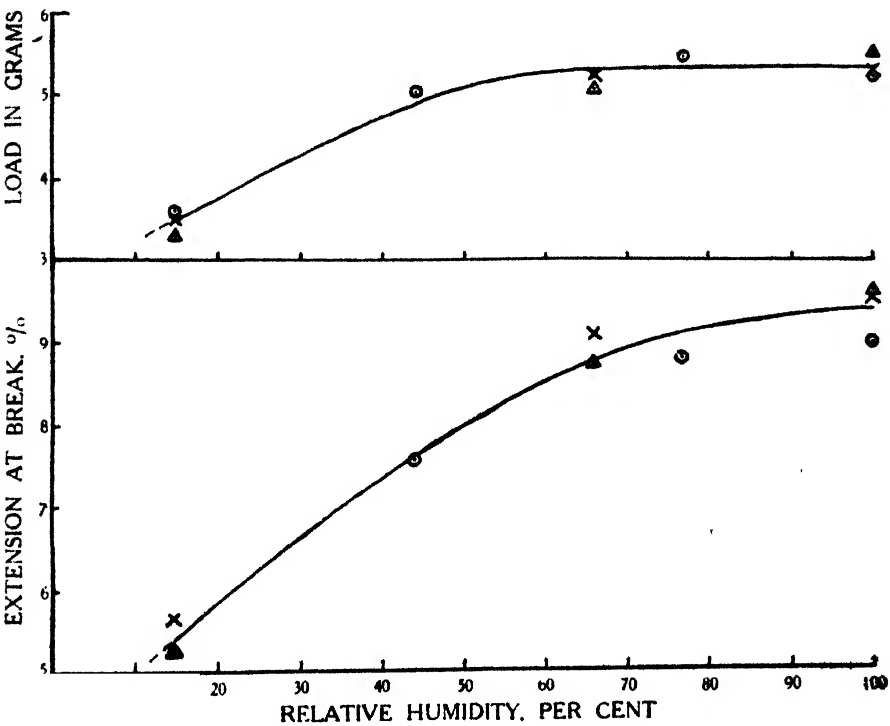

Fig. 1. Sakel cotton; means of 200 tests.

relation between the hair, yarn and fabric properties, made possible by this and other recent work, is deferred for another paper, but it appears that the elastic behaviour of the single hairs has a more dominant influence than is usually recognised.

Observations were also made on the effect of temperature on wet hairs, the wet condition being easy to maintain and of special significance. Rising temperature produces a slight weakening and increased extension. In the resistance to extension there is an apparent minimum, which may be real, since it is paralleled by other hair properties.

A history of the behaviour of each hair is recorded in the load-extension curve. Individual curves observed at one humidity vary in slope and length but have a fairly constant shape. Examples are shown in Fig. 2, and the average or composite curve constructed from each set of 50 is reproduced in Fig. 3.

A feature of interest immediately apparent in these curves is that the curvature is convex upwards. The form usually observed on imperfectly elastic material is concave, as in Fig. 2 for viscose. Such convexity is also observed in the behaviour of cotton yarn, and it may be ascribed to the known spiral

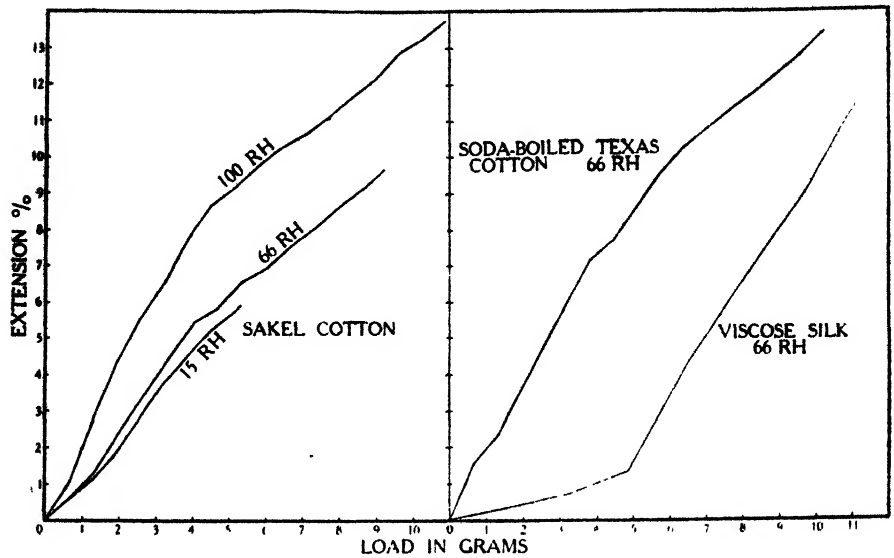

FIG. 2.

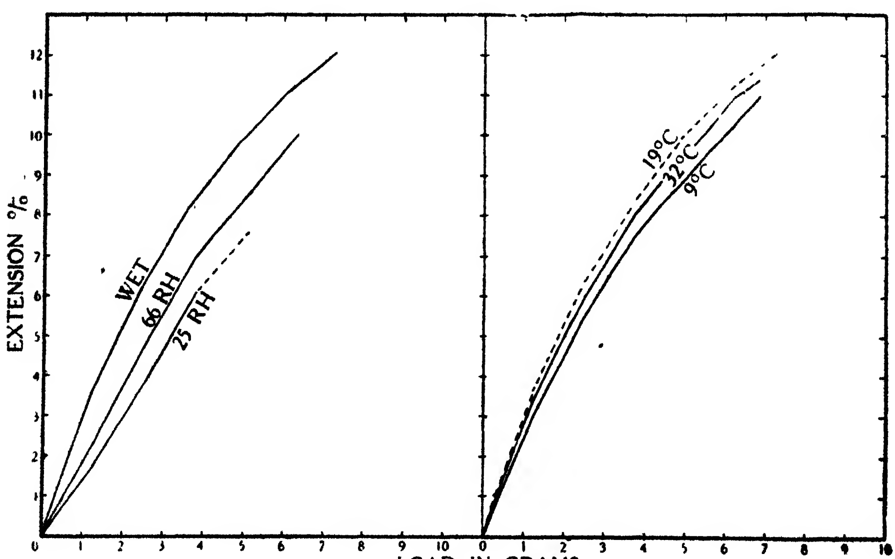

FIG. 3. Average stress/strain curves.

structure of the hair. It should further be noted that the slope of the curves of Fig. 3 is almost uniform when the load exceeds 3 or 4 grams, whatever the humidity or temperature. The differences lie in the amount of easy extension at low loads, which is greater in moister hairs. The extension in excess

of that corresponding to the later slope amounts to about 3% in wet hairs, 1% at 66% R.H., and is inappreciably small for the dry hairs. This may be ascribed to extension of the spirals, made possible by their swelling or separation by absorbed moisture. Then the true extension of the structural elements is represented by the later slope, and is unaffected by moisture. This insensitivity is indicated also by the fact that moisture does not weaken the hairs, and by other data reviewed in another paper.[7] The rise in breaking load may be explained by the lubrication of the elements, which facilitates a uniform distribution of stress.

Soda-boiled cotton extends more than the raw material, the difference again being in the initial convexity or structural effect. Cotton mercerised loose has a greatly increased extension, a mean of 13·9% against the 7·7% of raw cotton, which corresponds to the opening up of its internal structure. On the other hand, if a hair has been extended by previous loading, it resists further extension as strongly as in a continuous tensile test. The slope of recovery from load is also equal to the later uniform slope of the loading curves, i.e. it represents the elastic strain of the structural elements.

The intrinsic resistance of the material to extension is expressed by the quantity, Young's Modulus, in the calculation of which the cross-sectional area is taken into account. Values obtained from the initial slopes of the load-extension curves are given in Table IV. The Young's modulus for wet hairs is one-third that at 20% R.H., whereas the corresponding ratio for torsional resistance is one-ninth. The decreasing ratio of torsional to tensile elasticity is another example of the increase of anisotropy that has been discussed in relation to flexibility.[8]

Only with a knowledge of the load-extension relations for a representative sample of hairs is it possible to relate the strength of single hairs to that of bundles. The maximum load and the extension thereat of bundles of 50 hairs, uniformly mounted in parallel, were calculated for several samples. The bundle strength so calculated was about 50% of the aggregate strength. Actual bundle tests only realised some 30% of the strength, doubtless because the mounting and stretching were not sufficiently uniform, even with the greatest of care. The method described by Platt[9], of testing a compact tuft with a very short free length, gives a closer approximation to the actual condition of the hairs in yarn or fabric, and appears to give results of more real significance.

In a yarn each hair is supported by its neighbours, and its strength corresponds to that of a test length of less than a centimetre. The mean breaking load of Sakel and Zaria hairs in millimetre lengths was 60% and 85% greater than in centimetre lengths, the drop in strength of longer specimens being due to the variations along individual hairs. This internal variability may be separated by statistical theory from hair-to-hair variability, and it is sufficient to explain most of the apparent differences in the intrinsic strength of various cottons. As it has much less effect in yarn or fabric, little correlation is to be expected between the breaking lengths of hair and yarn in spinning tests on different varieties of cotton. At the same time these quantities will remain proportional after changes of strength produced chemically.

The effect of local flaws is shown up well and may be estimated by repeatedly breaking long hairs. At the third break, i.e. after eliminating two flaws, the breaking load had doubled, on an average, and trebled at the

sixth break. At the same time, the square root of the rigidity increased only 30 per cent. This quantity, and the hair-weight per centimetre, are determined mainly by the mean cross-section of the hair, the breaking load by the weakest flaw, and the extension at break by the ratio of the two. If two independent sources of variation are posited—mean area of hair and local weaknesses—the variabilities of the several dimensional and elastic quantities and the correlations between them, within a sample and between varieties, are reduced from chaos to order. Probably there is some degree of intrinsic variability in the cellulose itself, but that could only be observed after the effect of the coarser variations had been eliminated.

EXPERIMENTAL METHODS

The apparatus used was essentially Barratt's "Fibre Balance,"[1] the chief modification being in the method of applying the load to the specimen. Barratt made use of the attraction of a solenoid to a soft iron armature, but under certain conditions this method necessitated small corrections to the readings to allow for (1) variation in the results when the soft iron armature was sucked into the solenoid, and (2) variations due to hysteresis in the armature. To avoid these complications, the solenoid and armature were replaced by an O'Neill tube and float. The balance was a Sartorius chemical balance (sensitive to 0·2 mgm.) from which the scale pans had been removed.

The hair to be tested was mounted on torsion pendulums, to give a free length of hair of approximately 1 cm. The top pendulum was inserted in a small clip suspended from the left-hand knife edge of the balance, and the lower pendulum in a similar clip, the position of which could be adjusted by a rack and pinion arrangement. The float of an O'Neill apparatus was suspended from the other knife edge, the O'Neill tube being supported in a brass tripod. The O'Neill apparatus was calibrated in the usual manner.

The optical system for magnifying the extension of the hair was similar to that used by Barratt.[1] Two stainless steel mirrors were attached to the balance, one to the movable beam and the other to the fixed central pillar. A beam of light from a 100 watt gas-filled lamp, enclosed in a lamphouse, passed through a large double convex lens of —10 cms. focal length, was reflected three times from each mirror and then passed through a small double convex lens (focal length —40 cms.) immediately beyond the mirrors, eventually falling on a millimetre scale about 80 cms. away. The small lens was used to obtain the image on the millimetre scale of a cross wire stretched across the lens in the lamphouse. A metal shield with a small aperture cut in it was placed on the lamp side of the mirrors, to cut out any extraneous light. To obtain the maximum intensity of light, the filament of the lamp was focussed on the surface of the top mirror.

Efficient humidity control during testing was obtained by the use of the humidity control box described in a previous publication.[5] For this purpose the box was removed from the wooden stand on which it was mounted, screwed down to the bench, and the balance was placed inside. Once the optical system had been accurately focussed, the scale and lamp were also securely fixed in position. A black cloth, sufficiently long to cover the operator's head, was stretched from the end of the box to the scale, and as all windows in the box could easily be closed with shutters, the whole apparatus was thus enclosed in an efficient "dark room" whenever a reading of the image of the cross-wire was being taken.

The exit tube of the O'Neill apparatus was connected by rubber tubing to the stem of a T-tube, which passed through the end of the humidity box. One end of the cross-piece was connected to a reservoir of liquid and the other end to the jet through which liquid from the O'Neill tube was run out. In this way liquid could be run out of or into the O'Neill apparatus by manipulation of spring clips outside the humidity box. The jet of the O'Neill apparatus was attached to the end of a long length of rubber tubing, and was fixed to the end of the table near the millimetre scale, so that one operator could observe the movement of the image on the scale and run liquid out of the O'Neill apparatus at the same time. The jet was rigidly fixed in position, for any alteration would have altered the head of liquid flowing and so have altered the rate of loading.

The relative humidity in the box was controlled as in previous work[5] by solutions of calcium chloride. The lowest humidity was obtained by the use of phosphorus pentoxide, with a 60% solution of calcium chloride in the O'Neill apparatus, covered as before with a thin layer of B.P. paraffin. The actual R.H. thus obtained was determined by measurements of the rigidity of single hairs.

When investigating the effect of temperature, the hairs were tested at saturation, this being the most convenient R.H. to obtain at different temperatures. The determinations at 10° C. were carried out during two spells of cold weather. All radiators were shut off, the windows of the laboratory were opened, the hairs were conditioned in distilled water, and the dish containing them was placed over ice. Several other dishes of ice were put in the humidity box, and in this way it was found possible to control the temperature to within 2° C. There was usually a 2° C. difference between the temperature in the box and that of the conditioning water, and both temperatures were noted every few minutes; the temperature quoted is the mean of all these temperatures. The higher temperature was obtained by using electric radiator lamps behind or beneath the box, and in this way it was again found possible to control the temperature to within 2° C.

To determine the total magnification due to the multiple reflections from the mirrors and to the distance of the scale from the centre of the balance beam, a cathetometer was focussed on a fine mark made on the upper clip of the instrument, and simultaneous readings were taken on the cathetometer and the millimetre scale. The magnification was found to be 80·2 : 1.

Before the apparatus was used a careful investigation was made to show that there was no slipping of the pendulums in the clips. A short length of steel wire was mounted with shellac on two pendulums and fitted in the apparatus, the wire being of such a length and area of cross-section as to ensure a negligible extension under the maximum load (15 g. approx.) to which it could be subjected by the instrument. The steel was loaded to this maximum amount several times and no movement of the image on the scale was visible, although any slip would thus be magnified 80 times. This test was applied several times throughout the course of the work, to ensure that the clips continued to operate efficiently. This was also a severe test of the efficiency of shellac as a mountant.

The chief property measured was the extension of the hair at break, and to determine this for a particular hair, the instrument was manipulated as follows—

With the balance beam resting on its supports, the pendulums on which the hair was mounted were inserted in the clips, the lower clip being

sufficiently high to ensure that the hair was not strained. As it is imperative that the hair when under strain should be vertical, the lower grip was raised to ensure that the points of the pendulum tags coincided, if they did not the necessary adjustment was made to the lower pendulum. The balance beam was then raised from its supports in the usual manner. For ease in manipulation by one operator, the balance of the beam was adjusted so that the right-hand side of the beam (i.e. the side carrying the O'Neill float) tended to rise when the beam was set free, but the level of liquid in the O'Neill tube was at this stage always kept low enough to ensure that the float put sufficient load on the beam to prevent its right-hand side from rising. The operator next withdrew one arm from its arm-hole in the box and allowed liquid to run into the O'Neill tube from the reservoir, until the pointer on the balance came to zero on the lower scale. The rack and pinion were then adjusted until the hair became taut, as shown by a movement of one division of the pointer on that scale, so that a constant, but negligible, tension was put on each hair before beginning to test. The pinion was then clamped to prevent any movement when the hair was loaded. The original length (1) of the hair was measured by means of a cathetometer, and when this was being done a final check was made to ensure that the hair was vertical.

The shutters of the windows in the box having been closed, the reading of the image on the millimetre scale was noted and liquid run out of the O'Neill apparatus until the hair broke. While the hair was being strained, the image moved down the millimetre scale until at rupture it suddenly flashed out of view. A snap reading taken immediately before this happened, gave the final reading of the image on the scale. The breaking load of the hair was obtained from the volume of liquid run out of the O'Neill apparatus, and, the magnification of the instrument being known, the extension of the hair was determined from the deflection of the image on the millimetre scale. All extensions were expressed as percentages of the original length (l).

The hairs were sampled, mounted, and conditioned as in previous work,[5] and 200 observations were taken at each humidity and temperature. In all tests the rate of loading was 0·3 g. per second, so that the test occupied about the same time as the single-thread test on yarns.

To obtain load-extension curves, a metronome was used which rang a bell at regular intervals, about 2 or 4 seconds. The test was begun at one ring, and a reading of extension was taken at each subsequent ring till the hair broke. The rate of loading being known, a series of extension readings was obtained on each hair at equal intervals of tension.

RESULTS AND DISCUSSION

Effect of Humidity on Breaking Point

Stress-strain curves give a greater amount of information on the behaviour of hairs under load than the simpler tensile test for breaking load and extension, but are more laborious to observe. They were observed on Texas cotton in various states, and on Sakel. The variability of the hairs is so great, however, that a great number of extra tests for the breaking point only had to be done on Sakel, the more regular cotton, in order to obtain the effect of humidity on the breaking load and extension. All the results relating to this are shown in Table I and Fig. 1, the latter summarising the results of 2,000 simple tensile tests.

The effect on the breaking load of single hairs (Fig. 1) is in good agreement with that found in a previous investigation; it is appreciable at lower humidities, but inappreciable above 70% R.H., and it partly accounts for the effect on yarn strength.

Increasing humidity increases the ultimate extension that the hair can stand before rupture, the change being greater at lower humidities. The effect on extension is throughout greater than that on breaking load, so that the ratio of breaking load to extension continuously decreases with humidity, i.e. the hairs become more extensible. The change is again very similar to that observed on unsized yarn, and it is evident that the behaviour of the yarn is very largely determined by the tensile properties of the separate hairs, modified by secondary effects on the structure.

Table I

Effect of Humidity on the Breaking Load and Extension of Single Cotton Hairs at 19° C.

R.H. %	Breaking Load $F \pm 0{\cdot}1$ gm *	Extension % $E \pm 0{\cdot}1$	F/E** $\pm 0{\cdot}01$	Hair Wt. per cm. $\times 10^{-8}$ (gm.)
Sakel		FIRST SERIES—200 Tests. O		
100	5·30	9·00	0·586	149
77	5·55	8·81	0·638	,,
44	5·06	7·58	0·687	,,
15	3·63	5·26	0·724	,,
		SECOND SERIES—200 Tests. Δ		
100	5·60	9·63	0·589	133
66	5·12	8·76	0·601	,,
15	3·30	5·26	0·645	,,
		THIRD SERIES—200 Tests. ×		
100	5·38	9·54	0·566	143
66	5·30	9·10	0·599	,,
15	3·53	5·65	0·647	,,
		FOURTH SERIES—50 Tests.		
100	6·19	10·0	0·62	149
66	5·56	7·73	0·73	,,
25	3·34	4·38	0·77	,,
Texas		FIFTH SERIES—50 Tests.		
100	6·46	10·36	0·65	203
66	5·51	7·72	0·79	,,
15	3·80	4·01	1·03	,,

* Probable errors refer to tests on 200 specimens.

** F/E is the ratio of the breaking load to the extension of the same hair.

O, Δ, and × are the points marked on Fig. 1.

Effect of Temperature on Breaking Point

Table II shows the effect of temperature on the breaking point of wet Sakel hairs. In each series, a rise of temperature produces a decrease of breaking load and an increase of extension. The effect is too small to be determined as a percentage change with any great accuracy—the actual figures from the grand means for a rise of 1° C. are 0·3% of the value of breaking load at room temperature and 0·38% of the extension. It would hardly be safe to assert that the change is greater below 19° C. than above, but it may be since the rigidity effect is similar. The figure F/E accords with rigidity, swelling and water absorption in showing a minimum, but

the experimental arrangements were not suitable to test this point at higher temperatures.

In the observations at 31° C. there was a suggestion of insecurity at the grip, jumps of extension being noted before the breaking point. The mountant was pure shellac with a sharp melting point about 80° C., and microscopic examination of some suspect cases showed no signs of slipping; nor did these jumps occur any more frequently in strong than in weak hairs. The observations were probably real discontinuities in the extension, release of kinks, etc., which might occur without rupture in the hot, moist state. Similar jumps occur in the strain-time curves published by Collins.[4]

Table II
Effect of Temperature on Wet Hairs

Temperature	Breaking Load grams ±0·1	Extension % ±0·15	F/E ±0·01	Hair Wt. per cm. $\times 10^{-8}$ (gm.)
		First Series		
11·6° C.	5·27	8·34	0·641	133
30·8° C.	5·07	9·68	0·527	,,
		Second Series		
9·3° C.	6·10	8·82	0·685	148
31·1° C.	5·66	9·06	0·623	,,
		Third Series—50 Tests.		
8·9° C.	5·95	8·95	0·67	149
31·6° C.	5·54	9·39	0·61	,,
	Grand Means on all Sakel Hairs, Tables I and II.			
10·3° C.	5·71	8·62	0·664	—
19·0° C.	5·49	9·44	0·583	—
31·0° C.	5·38	9·37	0·579	—

Load-Extension Curves

The sets of 50 tests shown in Tables I and II were made by the method described for observing the load-extension relation. Owing to the smaller number of tests, the changes in breaking load and extension are not defined so exactly as in the larger sets, but they are of similar form. Their value lies in defining the shape of the curve connecting extension with load.

It is not practicable to present by curves or tables the observations on 50 hairs. If, however, the mean extension is calculated at each load, the resulting curve does not represent the average behaviour, but is unlike any of the individual curves, because of the different extensibility of strong and weak hairs.

In Fig. 2 some representative curves are shown. That taken to represent a set of tests is the one for which F/E at 2 g. load is near to the mean value, and which also shows a high breaking load. (Among hairs of the same extensibility, F/E, a high breaking load indicates comparative freedom from flaws rather than any difference in fineness). These curves have not been smoothed in any way, and each of the dozen or more points is an entirely independent snap reading. Their smoothness indicates a very satisfactory precision of observation, within about 0·1% of extension, or 0·01 millimetre.

The individual curves of any one sample were of very similar shape but varying slope, presumably because of variations of fineness of the hairs. The observation on each hair consisted of a series of extensions observed at

equally spaced intervals of load. The reading at one load, about 2 g., was taken as the unit for each series of extension readings, and the curves so plotted were closely coincident. The mean value at each load was found and multiplied by the mean value of the unit or standard extension. The curves of Fig. 3 were obtained in this way and are thus true representations of the average shapes. (It would have been better had the readings been taken and averaged at fixed intervals of extension rather than load, but the latter best suited the experimental method).

The most striking feature of these curves is their convex curvature, particularly marked in those representing the behaviour of wet hairs; at 19° C., for example, the hairs are more than twice as resistant to extension at the end than at the beginning. The usual experience with elastic materials is to obtain a straight line relation, while when the elasticity is imperfect, the material becomes more extensible as the load increases. This is seen in the curve for viscose rayon, which bends the opposite way from the curves for cotton.

Increasing resistance to extension may be explained by a spiral structure of separate filaments twisted round each other. Cotton yarn, especially an open, "oozy" yarn, shows a load-extension relation with this curvature still more marked, even at low humidities. The tension forces the fibres into contact and straightens them out in the direction of the yarn, so producing a structural extension which is added to that of the fibres themselves. When the latter are in close contact, their own extension only is recorded.

This explanation is in full accord with our knowledge of the structure of the cotton hair. The spiral elements of the hair-wall appear, in themselves, to be insensitive to moisture, which is absorbed between them, pushing them apart and weakening the lateral cohesion between them. So the wetter the cotton, the more open the spiral structure and the more is structural extension possible. The effect is confined to low tensions, for above 3 or 4 g. load the slope appears to be independent of changes of humidity or temperature. It is evident from the relation between breaking load and humidity that absorbed water does not weaken the longitudinal cohesion of the elements of the structure. All the effects could be explained by the separation and lubrication of these elements by the absorbed water, as shown in the observed swelling and decrease of rigidity.[2]

Table III

No. of Tests	Cotton	Hair Weight w 10^{-8} gm. per cm.	Breaking Load $F \pm 0{\cdot}2$ gm.	Extension $E \pm 0{\cdot}2\%$	Breaking Length F/w kilom.
50	Texas	203	5·51	7·72	27
50	Soda-boiled Texas	180	4·82	9·68	27
*200	Mercerised Texas	218	5·36	13·86	25
50	Sakel	149	5·56	7·73	37
400	Sakel	138	5·21	8·93	38
50	Viscose	843	11·19	29·28	13

* Mercerised loose in 15% caustic soda; breaking points only observed.

Observations were also made on a sample of soda-boiled Texas cotton (not the same cotton as the above sample of raw Texas). They show a greater ultimate extension and more marked curvature of the stress-strain relation than those on the raw cotton. In Table III results of tests at 66% R.H. on several materials are collected. One set of 50 tests does not make the mean

value a very exact description of the material as a whole, as may be seen from the two rows concerning Sakel cotton. It appears, however, that the latter extends more than Texas, but this does not imply a specific difference in the extensibility of the material of the hair wall, but rather that the weak elements or flaws that cause rupture are of about the same strength, so that the stress, and consequently the strain, at rupture is greater along the finer hairs.

Young's Modulus

To express the relation of extension to load as a property of the material of the hair wall, it must be expressed as a Young's Modulus, which is the ratio of stress to strain. The stress being the load per unit area of cross-section, the transverse area of the hairs must be evaluated. From work described in a previous paper,[2] this may be obtained at any humidity approximately enough for present purposes.

The hair weight of the Sakel cotton at 70% R.H. is 149×10^{-8} g. per centimetre; the moisture regain is 8·3% ∴ the dry hair-weight is $137{\cdot}4 \times 10^{-8}$ g. per cm. Taking the external specific volume at 0% R.H. as 0·65, the dry area of cross-section, $s = 89{\cdot}3 \times 10^{-8}$ sq. cm. The increase in area is taken as 3% for 10% R.H., 44% for wet hairs, and 1·5% for 10° C. rise of temperature for wet hairs. Any value of F/E is converted to a Youngs' modulus* by the formula—

$$q = \frac{F}{E} \cdot \frac{g}{s} \cdot 100 \text{ dynes/cm}^2 = \frac{F}{E} \cdot \frac{1}{s} \cdot 0{\cdot}9814 \cdot 10^5 \text{ dynes/cm.}^2$$

The value of F/E was found for each hair for the reading near 2 g., and their mean is given as the value of the slope at 1 g. load. The probable error of $100F/E$ is about 2.

Table IV

Conditions °C.	Conditions R H	Area sq. μ	100 F/E at 1 gm.	q 10^{10} dynes/cm²
		Sakel Cotton.		
19	25	96	83	8·5
19	66	107	67	6·1
19	Wet	129	38	2·9
9	,,	131	46	3·4
32	,,	126	41	3·2
	Texas Cotton.	Hair-weight at 70 R.H.-203×10^{-8} gm./cm.		
19	15	127	105	8·1
19	66	146	81	5·4
19	Wet	175	47	2·6
Soda-boiled Texas Cotton.		Hair-weight at 70 R.H $= 180 \times 10^{-8}$ gm./cm		
19	66	133	45	3·3
Viscose Rayon.		Filament weight at 70 R.H.$=843 \times 10^{-8}$ gm/cm. ($\rho = 0{\cdot}658$).		
19	66	555	223	3·9

Apparently the Texas cotton material has about 10% less specific resistance to extension than the Sakel, and the soda-boiled material is more extensible than the raw. The figure for viscose rayon is subject to some

* Like all moduli calculated from measurements on cotton hairs, the value so obtained is an "effective modulus," the fine structure and irregularity of the specimen being ignored.

uncertainty, since the external specific volume is not exactly known, but it is about the same as that for soda-boiled cotton. This applies only to the beginning of loading, however, as the Young's modulus of the cotton increases with load, whilst that of the viscose decreases.

The more a hair has been extended the greater is its Young's modulus, even when the extension is the residual from some previous loading. This can be seen from Fig. 4, one of a number of similar graphs obtained by

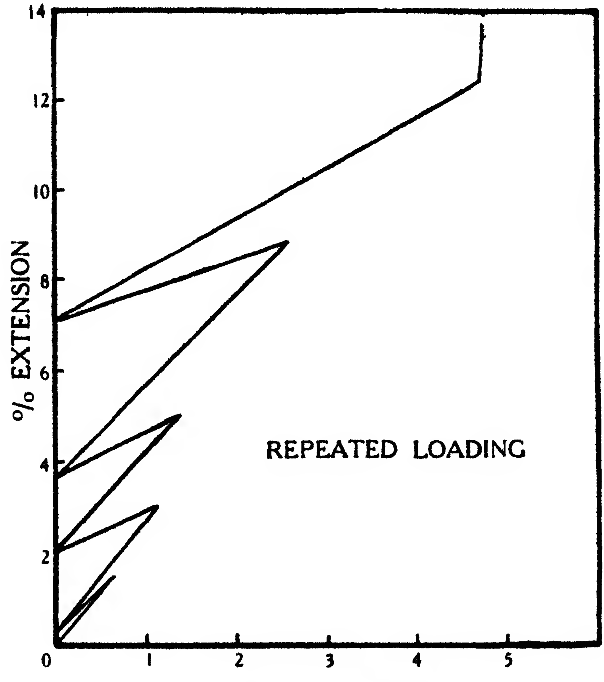

FIG. 4.

alternately loading and reloading Sakel hairs at 66% R.H. The recovery slope is the more constant, and is about equal to that of the loading curve near rupture. It probably represents much more closely the extension in total length of the spiral elements of the hair-wall, and gives a Young's modulus some three times the initial loading value shown above. In yarns, the hairs are under some tension produced by the twist, and have been extended somewhat in previous treatment, so that some intermediate value will determine the extension of yarns under load.

Bundle Strength

If a number of hairs is tested as a parallel bundle, the breaking load is not the sum total of those of the hairs, for they do not break simultaneously. Owing to the great variability in strength of single hairs, it would be a convenience to be able to test bundles and to know the relation between bundle and single breaking loads. The relation is also of interest in comparing hair and yarn strength. Turner[10] made calculations by assuming that the hairs broke in the order of their breaking loads, the actual order being that of ultimate extensions, and unknown. The data now found show that the relation between the load and extension at break is very variable, as shown by the correlation coefficients below (pp. T202–T203). Peirce[7] dealt

with the problem analytically, but only on certain assumptions which are not strictly true.

The bundle strength can be rigorously calculated only from a knowledge of the load-extension relations of all the hairs, as obtained in the present research. If the hairs are laid parallel and straight between two grips 1 cm. apart, they will be subjected to the same extension at any moment of the test. After all the observed curves for a set of 50 hairs had been plotted, the load at each 0·1 mm. of extension was read off, and the total tension on the surviving hairs of the bundle found. The resulting load-extension relation is shown on Fig. 5 for the tests on Sakel at 66% R.H.

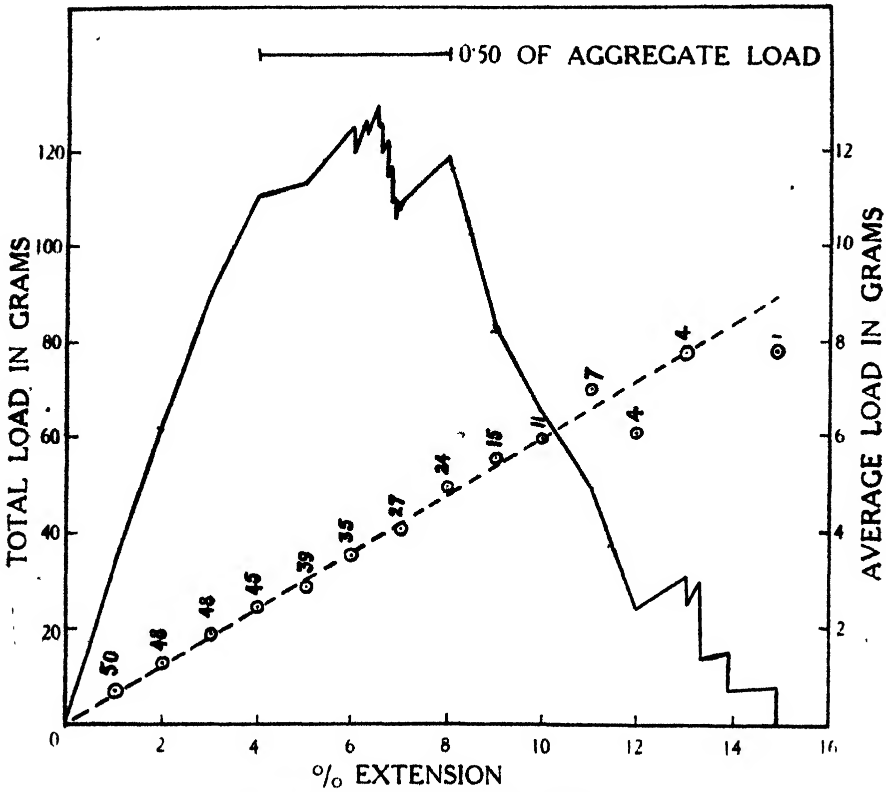

Fig. 5. Details for single hairs filled in between 6 and 7% and above 12% only.

The maximum load occurs at about 6% extension, where the load is 0·45 of the aggregate breaking load of the hairs. On the same graph is shown a plot of the average tension on the surviving hairs. This is practically straight, the curvature of the individual relations being corrected by the greater resistance to extension of the hairs which survive longer.

Five of the sets of load-extension tests were similarly analysed, with results shown in Table V.

The maximum load was determined only to the nearest unit of percentage extension, and the actual peak is slightly higher; by inspection, the mean would be close to 0·50 of the total load. The analytical relation gives the ratio as 0·57 for a standard deviation of 36%. Its derivation assumes a

Table V

Cotton	R.H.	Breaking Load grams	Standard Deviation %	Extension %	Standard Deviation %	Correlation Coefficient	Maximum Load	No. of Survivors	Maximum ÷ Aggregate Load	% Extension at Maximum
Texas	66	5·51	38	7·72	42	0·77	139	46	0·50	4+
Texas, soda-boiled ...	66	4·82	54	9·68	37	0·45	118	34	0·49	7−
Sakel	66	5·56	49	7·73	39	0·70	125	35	0·45	6+
Texas ...	Wet	6·46	42	10·36	38	0·49	131	34	0·41	8−
Sakel	,,	6·19	42	10·0	27	0·56	155	34	0·50	9−
Mean	—	—	45	—	36	0·59	—	37	0·47	—

linear relation between the extension and the mean load on the survivors, which is approximately true, and a normal frequency curve for extension.

Frequency polygons of extension of Sakel hairs at the driest conditions, at 66% R.H. and when wet are shown in Fig. 6. They approximate to the

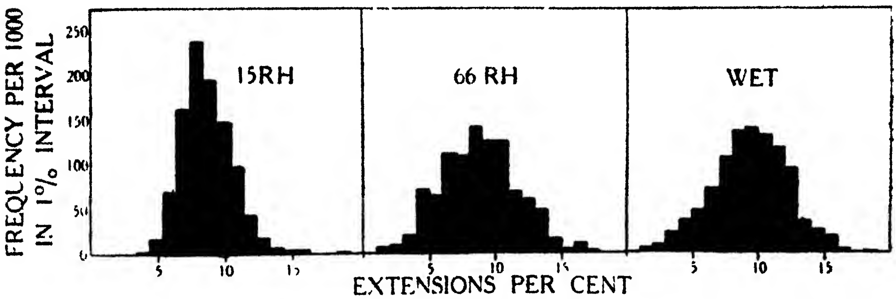

Fig. 6.

normal, but the bundle strength appears to be sensitive to deviations. Thus a low value group will be broken before the maximum is attained, but such a group contributes to the aggregate on which the ratio (maximum/aggregate) is calculated. Imperfect mounting will produce such groups, and this is the reason why it is difficult in practice to test hairs in bundles. Some tests were made on this point on tufts carefully brushed out and stuck down with celluloid cement, a method adopted by the American Society for Testing Materials. An alternative method was developed to grip the hairs at even tension. The tuft was stuck to adhesive tape by one end and the other stroked out by a rapidly revolving plush roller, then gripped by another piece of the tape. Two equal tufts of hairs were weighed out, each being tested in five approximately equal bundles of about 1,640 hairs. The first method gave a mean of 2·08 kgm., the second 2·28 kgm. Single hair tests gave a mean of 5·4 g., or 8·86 kgm. for 1,640. The second method has the advantage, but it only realises 27% of the total strength.

In another test, 100 bundles of 50 hairs each were made by the brushing method, and a mean breaking load obtained of 105 g. with a standard deviation of 15%. This represents 39% of the total strength. The failure to realise the theoretical of about 50% indicates variations of tension, including a tearing effect in testing, which have too much effect even on the most careful testing. (The tests were done on a heavy single-thread dead-weight tester, with special grips, swivelled to minimise tearing.)

Length of Specimen

One centimetre is a convenient length for test, as it leaves a sufficient tail at either end for the mounting of even the shortest hairs that are of much practical interest. It is, however, arbitrary, and greater than the effective length over which the break may occur in yarn or fabric. In a strong yarn or fabric the broken hair ends are localised within a millimetre or two by the composite weakness which determines the rupture. If test results are to be used in interpreting the strength of textiles, it is necessary to generalise them for any test length.

The relation between strength and length has been deduced by Peirce theoretically, and some experimental results have been recorded for Sakel hairs.[7] It is a function of the variability of strength along the single hairs, which must be deduced from the strength of two or more different test lengths. If a be the mean strength of the given length, a_1 of 1 millimetre lengths,

$$a = a_1 - v.\sigma_1'$$

where v is a known function of the length in millimetres and σ_1' is the standard deviation of the strength of 1 millimetre lengths of any one hair. The observed standard deviation, σ_1 is the square root of the sum of the squares of σ_1', and S the standard deviation of the average strength of the whole hairs, tested in millimetres. These two may be separately evaluated from either the means or standard deviations of 10 mm. lengths.

This has been done for two samples by observations on 1 mm. and 10 mm. lengths, 200 tests being made for each figure at 66 R.H.

Table VI

	Sakel Hairs	Zaria Hairs
Hair weight per centimetre ...	143	172×10^{-8} gm.
Breaking load of 1 mm. a_1 ...	8·29	7·76 gm.
Standard deviation, σ_1 ...	2·55	3·42 gm
% variability, σ_1/a_1 ...	30·8	44·0 %
Breaking load of 10 mm a_{10} ...	5·18	4·19 gm
Standard deviation, σ_{10} ...	2·22	2·65 gm
% variability, σ_{10}/a_{10} ...	42·8	63·2 %
Excess of a_1 over a_{10} ...	60	86 %
σ'_1/σ_1 from means of 1 and 10 mm. ...	0·72	0·68
σ'_1/σ_1 from standard deviations ...	0·69	0·78
Calculated value of σ' ...	1·80	2·50 gm
Calculated value of S ...	1·81	2·33 gm
Breaking length in kilometres—		
Observed for 10 mm. specimens ...	36	24
Calculated for 2 mm. ...	51	37
Observed for 1 mm. ...	58	45

The Sakel cotton is 50% stronger by weight than the Zaria, tested in centimetre lengths, but this superiority falls below 30% on 1 mm. lengths. Moreover, before testing the Zaria hairs in centimetres they were examined, and those containing obvious abnormalities, such as dog-leg bends, were noted. Seventy-two of these gave a mean of 2·6 g., the remaining 130 a mean of 5·1 g. Structures of this sort would not be such a source of weakness in the yarn as to the unsupported test specimen. It is probable that the actual intrinsic strength (breaking length) of the cotton wall, at the point where it breaks, is something like 60 kilometres, and that most of the differences shown by test are due to variability along the test specimen.

There may be minor differences such as are introduced by the varying proportion of primary wall, by the possibly greater regularity of growth-rings deposited slowly in finer cottons, and by tendering in the field before picking.

The arbitrariness of the single hair test and the practical difficulties of the bundle test lend interest to the method described recently by Pratt,[9] a modified bundle test in which a tuft is wrapped with sewing thread to localise the break at the middle, where 1/50th of an inch is left unsupported. The results given show a strength of 67,500 lb. per sq. in. of cellulose, which is equivalent to about 30 km. breaking length for a density of 1·55. The statistical relation between single hair and tuft breaks being taken into account, this is a reasonable yield from an intrinsic strength of 60 km., and is probably a good measure of that realisable in yarn form, when variability and slip are eliminated. The tests were done on 5 bales each of six varieties of American cotton, and no significant difference was shown between the varieties. Such facts explain the apparent paradox that, although the yarn strength falls off in direct proportion to the hair strength when yarn is chemically tendered, yet no correlation can be detected between hair and yarn tests as between varieties. Other things being equal, the yarn strength is proportional to the hair strength, but the latter is effectively invariable in unmodified cotton in yarn form, as compared with those other things that cannot be made equal.

The importance of local variability and imperfections may be demonstrated by repeatedly breaking the same hair. Sakel hairs were tested first over a length of about 3·6 cm., the longer fragment was re-tested, and so on till the last test was made on a length of about 0·8 cm. long. On 6 hairs, the mean of the first breaks was 2·52 g., and of the second 3·80 g., whilst after the removal of the two flaws causing these breaks the tensile strength rose to 5·15 g., or more than twice the original strength. After high breaks there is evidence of weakening, so that in Table VII the first breaking loads are compared with the maximum breaking loads measured.

Table VII

First Values				Maximum Break					
l cm.	F gm.	G	F/G	Order	l cm.	F gm.	G	F/G	F max/first
3·41	1·15	2·65	0·45	5th	1·00	5·19	4·35	1·22	4·5
3·79	1·42	4·19	0·34	7th	1·26	6·40	5·56	1·15	4 5
3·51	2·26	3·89	0·58	6th	0·79	8·68	6·01	1·44	3·8
3·57	4·62	5·65	0·82	3rd	2·96	6·99	6·27	1·11	1·5
3·74	3·14	4·85	0·65	7th	0·66	9·25	6·80	1·36	2·9
3·67	2·54	6·06	0·42	8th	0·84	7·94	6·86	1·16	3·1
Means 3·61	2·52	4·55	0·54	6th	1·25	7·41	5·98	1·24	—

l is the length in centimetres, F the breaking load in grams, $G = 100.\sqrt{1/T^2}$, where T is the time of oscillation in the rigidity test.

The quantity G may be expressed as the product of the cross-sectional area and a factor compounded of the ridigity modulus and a geometrical factor.[2] While the removal of five weak places trebles the strength, this square root rigidity quantity G only increases by 30%, and the final value is a good measure of the average coarseness of the hair. The value of F/G

is thus an index of regularity, and a high value denotes a relative absence of flaw. At the first break it is low and variable (maximum variation 52% of mean), while at the maximum break it is high and uniform (maximum variation 16%). In so far as varietal differences are due to flaws, it is therefore to be expected that a great breaking length or F/m will be accompanied by a high and regular value of F/G. The present work does not cover a range of varieties, and such relations are only indications of methods to be tried out on varietal comparisons.

The first mean agrees well with that calculated by formula from Table VI for a length of 3·6 cm., which is 2·89 g. It represents a breaking length of only 17·6 km. Plainly, strength tests on cotton hairs are largely determined by the incidence and magnitude of local weaknesses, the effect of which must be first considered in interpreting the results, whether the point of interest is intrinsic strength, varietal differences, or textile quality.

Correlations

For obvious reasons, no measurements were made on the extension of 1 mm. specimens. Extension is, however, an additive property, the summation of the extension of all the elements of the length. A local flaw has little effect on the load-extension relation except to cut it short. When the extension is expressed as a percentage, the curves for 1 cm. specimens are therefore valid for any length, and the breaking extension is given by the intercept at the breaking load corresponding to the test length.

Variations of test results among the hairs of a sample arise principally from two sources, the average cross-section and the occurrence of flaws. We have seen that the latter is a very material factor, and its effect is evident in the correlation arrays, so far as they can be determined, of the quantities cross-sectional area s, hair weight per centimetre m, breaking load F, final extension E, the ratio F/E, and the square root rigidity quantity G. For uniform hairs, the following relations would hold—

$$m=\varrho s,\quad F=fs,\quad E=e,\quad F/E=f/e.s,\quad G=gs,$$

where ϱ, f, etc., are constants of proportionality. For the same hair in which a local flaw occurs which effectively reduces the cross section to s', m is unaffected, F/E and G are slightly and about equally affected, while F and E are reduced in the ratio s'/s.

Weighings and rigidity tests were sometimes made to ensure uniform sampling, and these showed a consistent and high correlation between F and G, a much poorer one between F and m, and an intermediate correlation between G and m. The variations of m could not be measured individually but only on groups of 20 hairs. Great care was taken to ensure random and individual sampling of the hairs, and, by repeated weighing, to eliminate observational variation. The results of an experiment on three very different samples made especially to test the relations between m, F, E, F/E, and G are shown in Table VIII.

The variability of m is found by multiplying by $\sqrt{20}$ that found for groups of 20. It isolates the variations of mean cross-section (i.e. of s), and its mean value is 31%. The variability of E isolates that due to flaws (i.e. of s'/s), and is 35%. These two are practically the two independent sources of variation referred to above, and are about equal. The variability

Table VIII

	Breaking Load F	Extension E	F/E	G*	Hair Wt. per cm. m
Mean values on 200 hairs—					
Sakel	5·30 gm.	9·10%	0·599	0·118	138×10^{-8} gm. per cm.
Soda-boiled Texas ...	4·73	8·97	0·562	0·165	195
Mercerised Texas ...	5·36	13·86	0·428	0·232	218
Standard Deviations as percentages of means—					
Sakel	41	29	39	37	26
Soda-boiled Texas ...	56	37	55	52	45
Mercerised Texas ...	47	39	47	44	22
Averages	48	35	47	45	31

Correlation coefficients, between individual variations—	$F/E:G$	$F:G$	$F:E$	$E:G$
Sakel	0·61	0·63	0·40	0·08
Soda-boiled Texas ...	0·68	0·66	0·33	−0·02
Mercerised Texas ...	0·76	0·67	0·31	−0·23
Averages	0·68	0·65	0·35	−0·06

Correlation coefficients, between means of 20 hairs—	$G:m$	$F/E:m$	$F:m$	$E:m$
Sakel	0·60	−0·15	0·06	0·24
Soda-boiled Texas ...	0·87	0·59	0·84	0·26
Mercerised Texas ...	0·32	0·46	0·15	−0·24
Averages	0·60	0·30	0·35	−0·06

* $G = 100.\sqrt{1/T^2}$, where T is the time of oscillation in the rigidity test.

of F involves both equally, and shows the highest value, with an average of 48%. The elastic properties, F/E and G, are affected in a less degree and about equally by the flaw variation, and should have intermediate values. The degree of correlation of two quantities may be anticipated from the degree to which they are subject in common to the two independent variations. Thus F/E and G are similarly subject to both, and should be strongly correlated; E is subject primarily to flaws, G to area, so their correlation should be small. In the table, the pairs are arranged in order of their expected magnitude, and the expectation is realised. Those involving m are less consistent, as only 10 mean group values are available.

If the strength of 1 mm. lengths is taken as a measure of the effective local section, the data of Table VI give parallel information on variability. The mean area variability is measured by s, which is 22% and 30% for the Sakel and Zaria respectively. The imposed variability due to local flaws is measured by σ_1', which is 22% and 32%. Reference may also be made to the variability of cross-sectional area found by Clegg and Harland,[3] which was 35% for a Texas cotton. This depends on local, not mean, values, but is not affected by flaws, and so gives an upper limit for the area variation.

In fine, there is every indication of two independent variables, mean area and local flaw, which determine the tensile and elastic properties of cotton in roughly equal degree. Variations within a sample are correlated in accordance with their dependence on these two variables. No doubt some variation exists in the specific properties of the cellulose also, but the above analysis indicates the main features of the observed variability. Differences in specific strength, extensibility, etc., between varieties can also be largely explained as the effect of flaws, rather than of intrinsic specific differences in the cellulose. The latter are of considerable interest, but their study demands data less subject to the grosser structural variability than those brought forward here.

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THE JOURNAL OF THE
TEXTILE INSTITUTE
TRANSACTIONS

12—THE SPINNING VALUE OF RAW COTTON

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INTRODUCTION AND SUMMARY

It was hoped that the experiments described in this paper would throw some light on the factors which determine yarn quality from the point of view of the raw material. Unfortunately, unavoidable circumstances arose which made it impossible to complete the scheme of research as originally planned, so that the conclusions have had to be based on observations on a limited number of both hair and yarn properties. Nevertheless it is felt that such results as have been obtained, bearing, as they do, on the work already published by Balls[1] and Turner[13], will be of interest and use to future investigators, and to that end this report is presented. During 1926, fifteen different cottons were obtained, representing a considerable variety of origin, and in order to simplify the investigation somewhat, an attempt was made to eliminate the effect of hair length by choosing cottons of nominally the same staple. These cottons were spun into a range of yarns of different counts and twist, and the results of the strength tests on the yarns were examined in relation to certain of the measurable characters of the raw materials.

The following are the more important of the conclusions reached, the assumption being made that mean hair length is constant--

(1) Yarn regularity depends on hair fineness to a greater extent than on any other easily measured hair property. The influence of staple length regularity is relatively insignificant.

(2) From the point of view of utility, the strongest yarn is obtained from most $1\frac{1}{8}$ in. cottons when the spinning constant is approximately 3·6.

(3) Where it is necessary or desirable to use low spinning constants, fine cottons give strengths more nearly approaching their maximum than do coarse cottons.

(4) All other things being equal, fine cottons are capable of being spun to higher counts than are coarse cottons.

(5) Yarn strength is apparently not at all affected by hair strength because of the masking effect of irregularity, and thus the strongest yarn will be produced not from the *strongest* cotton, but from the *finest*.

PARTICULARS OF THE COTTONS USED

Through the courtesy of the Liverpool Cotton Association a series of 15 different cottons, were obtained, the staple lengths of which were as nearly as possible $1\frac{1}{8}$ in. nominal. Actually, these were found by measurement to vary somewhat, and consequently differential treatment had to be accorded to the samples in the drafting. This has been taken into account in the analysis of the results, for the only alternative would have been to conduct a separate series of preliminary experiments to determine the most suitable

roller settings for each cotton. Since only 10 lb. of each sample were available this was impossible.

The cottons were selected to give the widest possible range of fineness, since it was anticipated that this would be the most important of the hair properties, and since other characters have already been shown to be closely related to it. The hair weight per cm. used throughout this work as a measure of fineness ranged from 160 to 261 (mg. $\times 10^{-5}$ per cm.)

In Table I are given the names of the cottons chosen, letters by which they are identified in the text, and particulars of such hair characters as have been measured or deduced.

Table I

Hair Characters of the Fifteen Cottons

Variety (Samples obtained in March 1926)	A Mean Length mm.	B Mean Breaking Load g	C Hair Weight per cm mg $\times 10^{-5}$	D Standard Deviation % Length	E Standard Deviation % Breaking Load	F Col. B ÷ Col C $\times 10^{4}$	G Modal Length
A Texas	22·7	5·05	195	28·2	47·9	2,719	26·0
B Memphis	22·8	4·37	184	22·4	47·8	2,375	24·5
C Arizona	22·0	5·04	202	35·0	42·4	2,495	26·0
D Punjab-American ...	20·6	4·86	182	32·0	45·4	2,670	20·5
E Zaria	19·8	3·90	162	29·8	52·0	2,408	24·0
F Rio	23·1	5·67	176	29·4	43·1	3,210	26·0
G Queensland Durango	20·5	4·46	160	32·2	44·2	2,788	25·0
H Smooth Peruvian ...	20·8	4·46	191	36·2	40·7	2,337	25·6
I S. African	19·8	4·34	197	29·8	46·3	2,201	23·2
J Iquitos	21·4	6·65	261	31·3	42·2	2,549	25·0
K Pernams	21·0	5·53	190	32·4	45·7	2,912	24·0
L Dharwar No 1 ...	20·5	4·43	229	23·9	42·2	1,934	21·0
M Sircar	19·0	5·57	238	30·0	43·7	2,340	21·4
N Texas	20·8	5·07	221	26·5	49·5	2,293	21·0
O Memphis	20·6	4·56	239	25·2	46·5	1,910	24·0

OUTLINE OF SPINNING PROCEDURE

The spinning of the cottons was carried out in the College Spinning Room under the supervision of Mr. Winterbottom. Unfortunately, owing to the fact already mentioned that all the cottons had not the same length characteristics, it was impossible to give them all identical treatment in the later processes. Up to the finisher sliver, however, they were passed successively through the same machines, namely—single Buckley and scutcher opener combination, scutcher, card (stripped clean before each sample was treated), and three passages of drawframes. Sample A was treated first and subjected to a second scutching, but the resultant lap showed slight evidence of "rat-tailing," and therefore subsequent samples were scutched once only. It was considered that the double scutching of sample A would not appreciably affect the quality of the ultimate yarn. All the samples were spun at the same time on a variable-speed twist ring frame under conditions in which the temperature was maintained within the range of 71°–78° F., and the relative humidity within 52%–70%. The following yarns were spun (from single roving) and four bobbins of each type were made from each sample—

Counts 24's with twist constants 3, 4, 5·5, and 7.

Counts 32's with twist constant 4.

Counts 40's with twist constant 4.

These are referred to as 24's/3·0, 24's/4·0, 24's/5·5, 24's/7·0, 32's/4·0, and 40's/4·0 respectively.

Particulars of settings, etc., are given in Appendix I (Experimental Details).

HAIR PROPERTIES AND YARN IRREGULARITY

In the endeavour to investigate the connection between the hair characters and the spinning value of raw cotton, it is essential first to define "spinning value." The value of a yarn lies primarily in (i) the way in which it stands up to the strains of further processes such as weaving and knitting, and (ii) the quality of fabric which can be made from it, but these characteristics cannot be described in terms of any one simple yarn property. The most

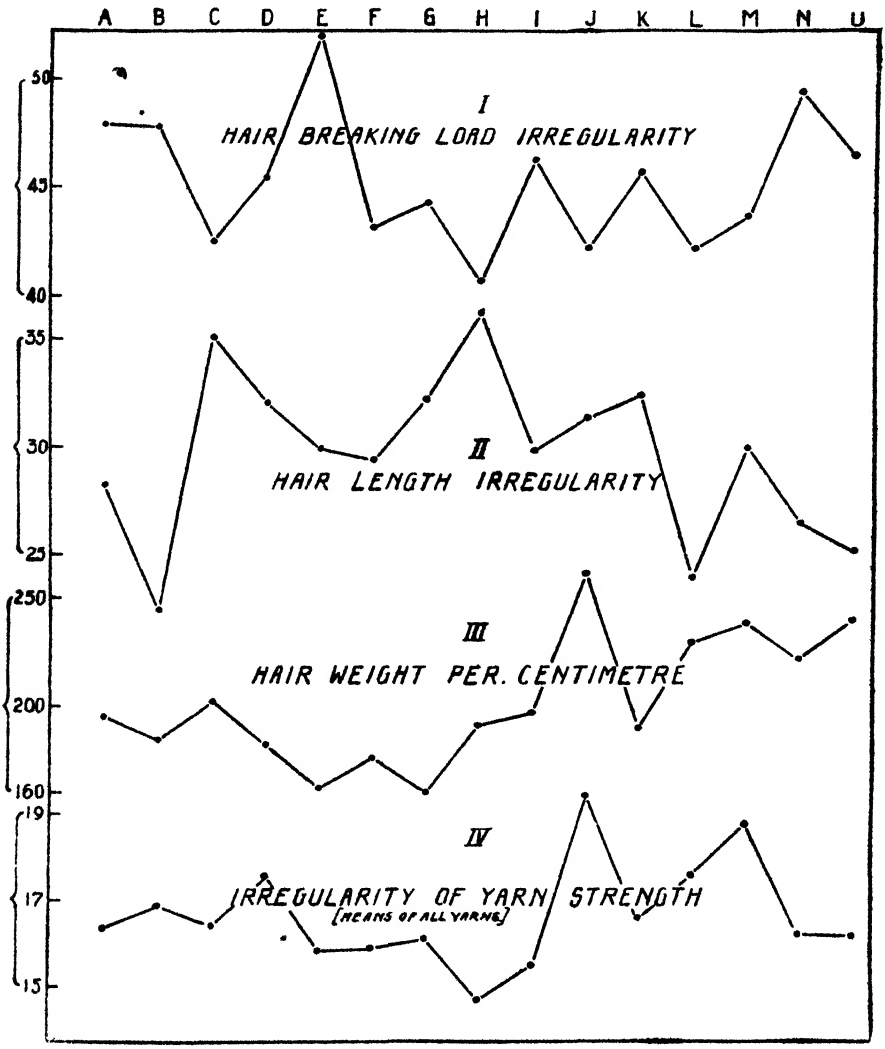

FIG. 1

commonly used figure, of course, is the strength, but complications are encountered owing to the fact that the value for observed strength falls off as the test length increases, owing to the greater chances provided for the occurrence of weak places.[12] Thus, strength is intimately connected with irregularity, and in the following pages an attempt will be made to relate hair properties to the irregularity of yarns—measured by the standard

deviation %—and later to the strength, expressed as the "breaking length" or product "count × strength."

In Fig. 1 are plotted for each cotton the coefficients of irregularity for hair length and hair breaking load, together with the mean coefficient of yarn strength irregularity (I, II, and IV). The results are presented here in this manner to serve only as indicators of possible relationships and not as final proof, but it is evident that no relationship exists among these three variables; or, in other words, the general belief that irregular cotton produces irregular yarn is not substantiated. It would be unsafe to say from this that irregularity of staple has no effect whatever on yarn regularity. What the results do imply is that, if the effect does exist, it is small as compared with the effects of other properties.

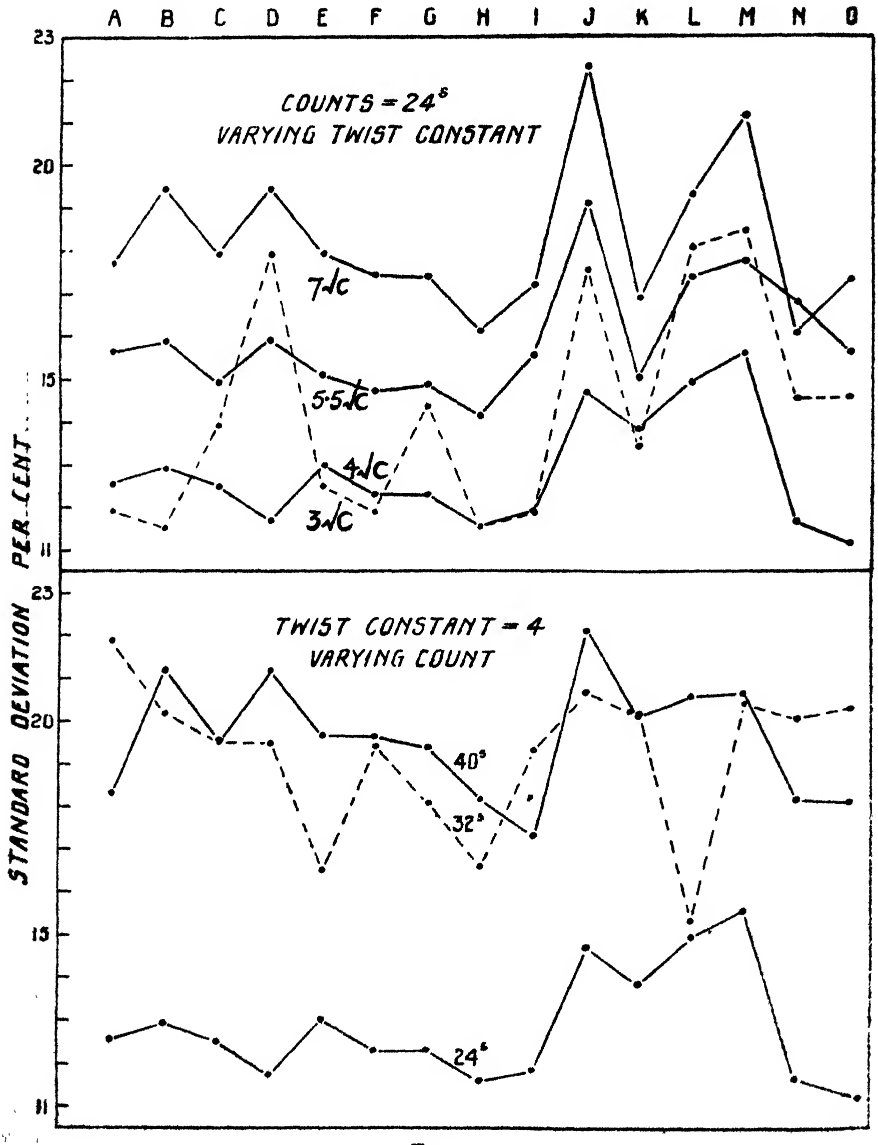

Fig. 2

The effect of *mean* hair length on yarn irregularity cannot be assessed, owing to the fact that the range of staples was deliberately chosen to be as small as possible. The experimental error alone would therefore vitiate any apparent relation. Fineness, however, is shown by these results to have a definite bearing on yarn irregularity as may be seen by reference to the third plotting in Fig. 1, the correlation coefficient between hair weight per cm. and average yarn irregularity being +·64. This is probably due to the greater number of hairs in the cross-section of a yarn spun from a fine cotton and the consequent greater possibility that each cross-section contains a perfect sample of the bulk, but it should be recognised that fineness may also exert its influence in this respect indirectly through the operation of some other hair property or properties, which may be associated, but which have not been measured in the present work.

TWIST AND YARN REGULARITY

In the above discussion attention has only been given to the *mean* irregularity of the six yarns into which each cotton was spun. Fig. 2, in which the separate yarn irregularities are plotted, shows that the relative contours for the 24's yarns with twist constants 4·0, 5·5, and 7·0 are all very much alike, but that the general degree of irregularity displayed becomes greater as the twist increases.

The increase in irregularity for each cotton when the twist constant is raised from 4·0 to 7·0 is given in Table II. When classified in order of increasing magnitude the values fall into the following order—

Up to 40%	K, L, M, N, E, H
40%–50%	A, G, F, C, I
50%–60%	B, J, O
Over 60%	D

This particular order does not appear to be attributed to any of the hair properties recorded in Table I.

Table II

Percentage Increase in Irregularity of 24's Yarn on increasing the Twist Constant from 4·0 to 7·0

A	41	F	42	K	23
B	51	G	42	L	30
C	43	H	39	M	36
D	67	I	46	N	37
E	39	J	52	O	54

The plotting for the 24's/3·0 yarn (Fig. 2) shows that the strength irregularity does not continue to decrease with decreasing twist constant, but on the contrary tends to increase again in spite of the lower spindle speed used (see Appendix I). Further, this increase is more marked in the case of the coarser cottons. It seems likely, therefore, that finer cottons tend to hang together more easily than coarse ones, and that with a twist constant of 3·0 the coarse cottons are not so easily able to withstand the spinning tension and consequently give a more irregular yarn. At the same time, it is recognised that the unmeasured surface properties of the hairs must also enter into the consideration.

Count and Yarn Irregularity

The coefficient of irregularity of single thread strength for each cotton is plotted in the lower part of Fig. 2 for varying counts of yarn all spun with a

twist constant of 4·0. Unfortunately the three graphs do not show the same consistency of outline as do those for constant count and varying twist. The 40's curve is similar in shape to these latter, but the 32's, except for a tendency to a peak at J and a dip at H, is very much much different. This anomaly

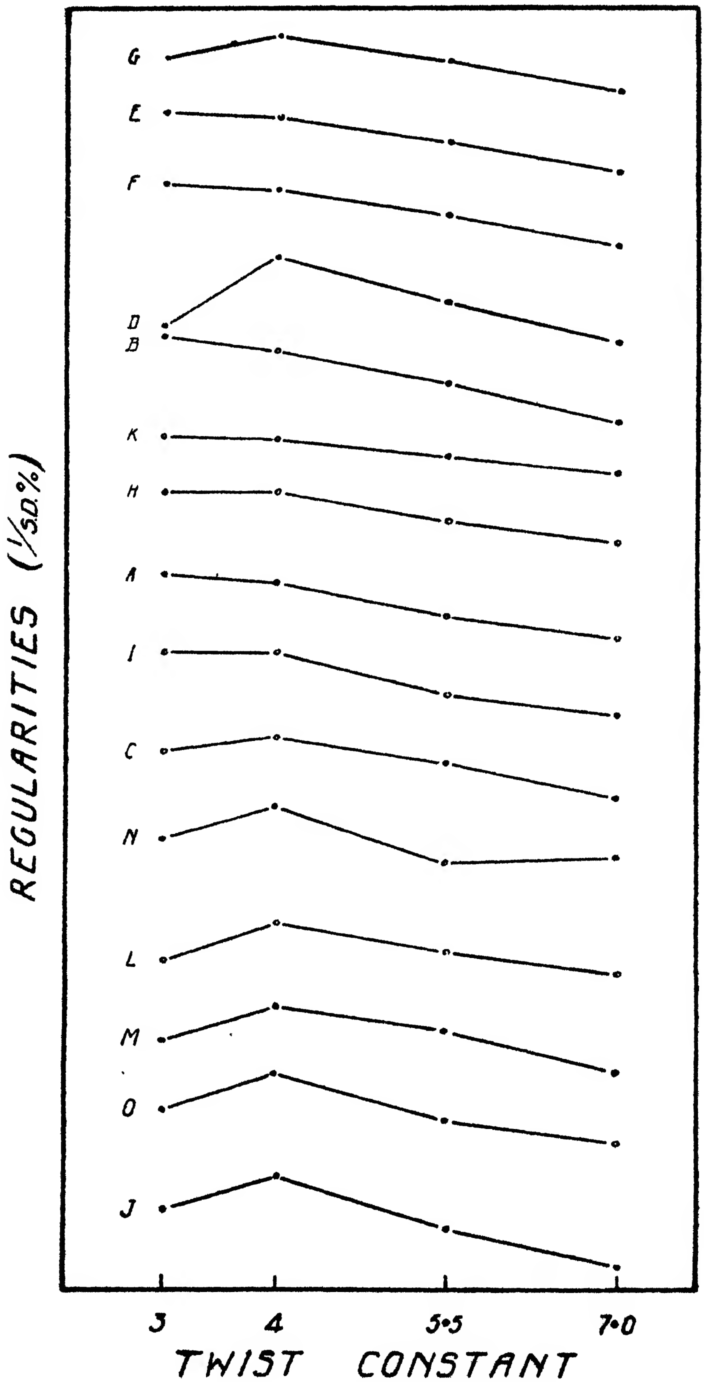

Fig. 3

must for the present remain unsolved as the data collected in this research provide no explanation of the fact that four of the cottons are definitely more regular in 40's than in 32's.

Comparison of the percentage increases in irregularity given in Table III with the hair weights per cm. given in Table I show that no relation exists between the two quantities.

Table III

Percentage Increases in Irregularity on increasing the Count from 24's to 40's with a Twist Constant of 4·0

A ... 36	...	F ... 60	...	K ... 46
B ... 64	...	G ... 58	...	L ... 38
C ... 57	..	H ... 57	...	M ... 33
D ... 81	..	I ... 47	...	N ... 55
E ... 52	...	J ... 50	..	O ... 62

If the values are classified similarly to those in Table II, the following order is obtained—

Up to 50%	M, A, L, K, I
50% to 60%	J, E, N, C, H, G
60% to 70%	F, O, B
Over 70%	D

Comparison of the figures in Table II with those in Table III might seem to indicate that those cottons of which the yarns become more irregular with increasing count are also those for which increasing twist constant has the same effect. While it is possible that this may be so, no such conclusion may legitimately be drawn from these results, for it can be shown that any correlation between the two series of figures is largely due to their dependence on the common value for the irregularity of the 24's/4·0 yarns.

The Effect of Hair Properties on the Reaction of Yarn to Twisting

It is already well established that the insertion of twist adds strength to the yarn up to a point, but that beyond a certain number of turns per inch the strength falls off again. The optimum turns per inch, moreover, is dependent on the particular kind of cotton used, as evidenced by the fact that the commonly used twist constants are different according to whether the cotton is Egyptian or American. In practice, length of staple is one of the determining factors, but its effect could not be measured in the present work owing to the very narrow range of staples employed. It was thought, however, that factors other than length might play an important part and in this section the evidence provided on this point is examined.

For convenience of reference, the yarn irregularity results may be plotted as shown in Fig. 3, the plottings being arranged in order of the fineness of the cottons. It will be observed that there is a general tendency for the coarser cottons to increase in regularity from soft twist to normal twist, and then to decrease as the twist continues to rise. It would also seem that with the exception of cottons G and D* the mode has a general movement to the right as the hair weight per cm. increases. This is illustrated on Fig. 4.

In the case of the coarse cottons, then, the rise to peak strength with increasing twist is likely to be sharper but later, i.e. in so far as yarn strength

* The disparity between the roller setting and the modal length is greater for sample D than for any of the other cottons. See Appendix I.

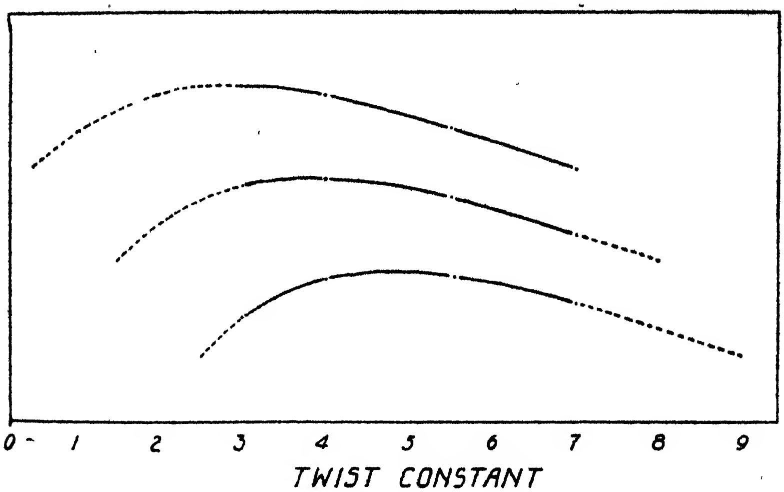

FIG. 4

Table IV

Single Thread Tests

Cotton	Single Thread Breaking Length (Hanks) 24's/3·0	24's/4·0	24's/5·5	24's/7·0	32's/4·0	40's/4·0	Irregularity (S.D.% of Single Thread Strength 24's/3·0	24's/4·0	24's/5·5	24's/7·0	32's/4·0	40's/4·0
A ...	15·07	18·38	18·80	14·65	15·70	16·18	11·9	12·6	15·7	17·7	21·8	18·3
B ...	17·93	18·75	17·71	14·72	16·70	16·31	11·5	12·9	15·9	19·5	20·2	21·2
C ...	16·25	19·45	17·61	15·04	15·94	16·33	13·9	12·5	14·9	17·9	19·5	19·6
D ..	13·30	17·51	18·32	15·83	15·32	15·77	18·0	11·7	15·9	19·5	19·5	21·2
E ...	15·83	18·56	17·39	14·80	16·04	16·30	12·5	13·0	15·1	18·0	16·5	19·7
F ...	16·83	20·46	18·68	15·18	16·45	16·65	11·9	12·3	14·7	17·5	19·4	19·7
G ...	16·02	18·72	18·76	15·89	16·49	17·01	14·3	12·3	14·9	17·4	18·1	19·4
H ...	16·66	17·18	17·37	14·99	15·85	16·68	11·6	11·6	14·2	16·1	16·6	18·2
I ...	13·74	16·70	15·97	14·20	13·94	15·18	11·8	11·8	15·6	17·2	19·3	17·3
J ...	10·37	14·27	15·10	16·19	10·99	12·49	17·6	14·7	19·1	22·3	20·7	22·1
K ...	14·87	17·00	16·39	14·41	14·46	15·18	13·5	13·8	15·1	16·9	20·2	20·1
L ...	12·35	17·01	16·87	15·07	12·22	15·31	18·1	14·9	17·4	19·3	15·3	20·6
M ...	9·88	15·48	17·05	15·07	11·37	13·30	18·5	15·6	17·8	21·2	20·4	20·7
N ...	12·80	16·81	16·49	14·81	13·43	15·38	14·5	11·7	16·8	16·0	20·1	18·2
O ...	14·18	17·99	16·90	15·14	14·50	15·67	14·6	11·2	15·7	17·3	20·3	16·1

is affected by irregularity, coarse cottons might be expected to demand a higher twist constant than fine ones. Verification of this is provided in Fig. 5, in which lea breaking length is plotted against twist constant. Cotton D is the only really outstanding exception. In Fig. 6, however, in which the single thread breaking length is plotted in a similar way, the movement of the mode shows no regular tendency as the hair weight per cm. increases, though it is interesting to note that Cotton J, the coarsest, has apparently not reached its maximum single thread strength even with the twist constant of 7·0.

The reason for the non-agreement as between Figs. 5 and 6 may be found in the fact that the values of single thread strength are not so susceptible to the effects of yarn irregularity as are those of lea strength. Thus to take an extreme case, if the yarn could be tested over infinitely short lengths, the strengths of the very strong places would be averaged with the strengths of the very weak places, and the resultant mean would be almost entirely independent of yarn regularity. Such a measure of yarn strength, however,

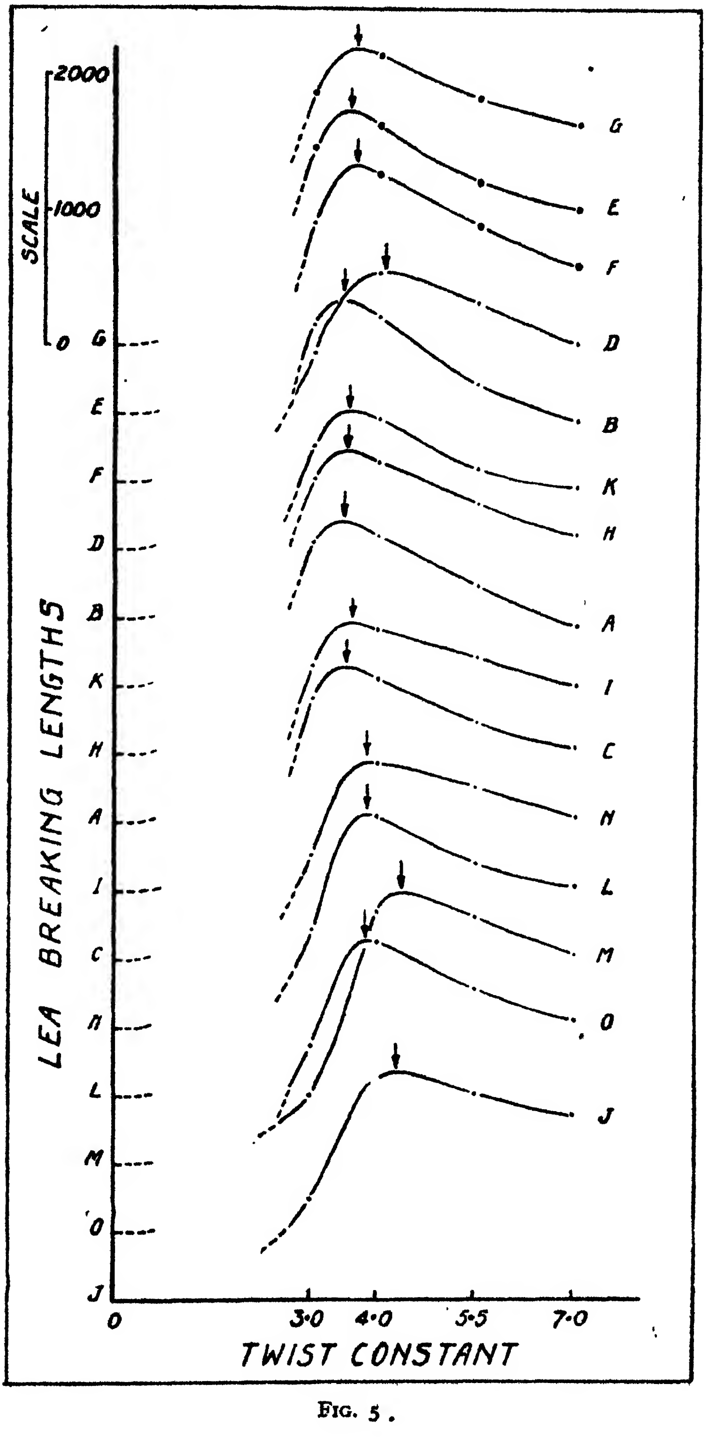
SCALE
2000
1000
0
LEA BREAKING LENGTHS
G
E
F
D
B
K
H
A
I
C
N
L
M
O
J
0
3·0
4·0
5·5
7·0
TWIST CONSTANT

FIG. 5.

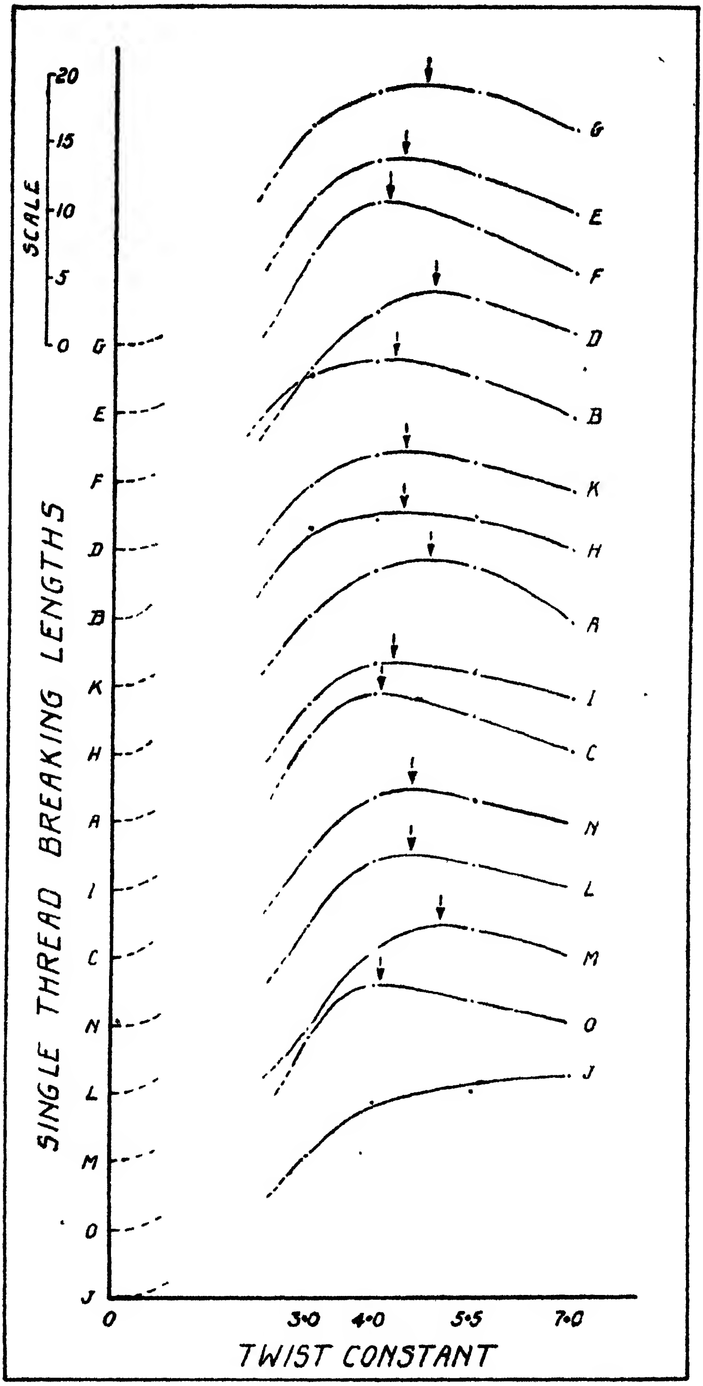
SCALE
20
15
10
5
0
SINGLE THREAD BREAKING LENGTHS
G
E
F
D
B
K
H
A
I
C
N
L
M
O
J
0
3·0
4·0
5·5
7·0
TWIST CONSTANT

FIG. 6

would be of no practical value, since it is the extent of the weaknesses which determines yarn utility. For this reason, more weight should be given here to the lea test results than to the single thread test results.

Table V

Cotton	24's/3·0	24's/4·0	24's/5·5	24's/7·0	32's/4·0	40's/4·0
A	2,081	2,117	1,755	1,484	1,837	1,645
B	2,170	2,221	1,723	1,469	1,861	1,594
C	1,935	2,082	1,750	1,584	1,802	1,662
D	1,584	2,051	1,825	1,539	1,793	1,628
E	1,963	2,131	1,725	1,518	1,817	1,652
F	1,922	2,283	1.906	1,608	1,898	1,688
G	1,886	2,152	1,850	1,658	1,857	1,653
H	2,049	2,167	1,863	1,633	1,880	1,611
I	1,673	1,943	1,722	1,525	1,726	1,513
J	737	1,617	1,507	1,369	1,358	1,077
K	1,793	1,986	1,612	1,489	1,647	1,519
L	1,239	2,049	1,706	1,546	1,695	1,460
M	509	1,885	1,817	1,542	1,383	1,017
N	1,274	1,951	1,775	1,545	1,682	1,514
O	1,380	2,139	1,799	1,560	1,734	1,568

The same explanation may be given for differences between the curves shown in the two figures. The lea test curves not only slope more sharply on either side of the mode, but also place the modes in general further to the left than do the single thread test curves. The former show the optimum twist constants to range from 3·4 for B to 4·4 for M. Ten out of the 15 values fall between 3·4 and 3·8—appreciably lower than the standard constant of 4·0 as commonly used in the industry.

The attainment of maximum yarn strength, however, is not the only aspect of the twist problem. Judging from the results obtained by Corser and Turner[5], there are strong reasons for believing that, in certain structures of cloth, single yarns as well as double yarns should be soft twisted to produce the strongest fabric. Certainly the softer yarn makes for better appearance and feel, especially in knitted fabrics. The best cottons to use, therefore, are likely to be those which attain most nearly to their maximum strength in yarn form when the turns per inch are low.

To study the results given by the 15 cottons in this connection, the values for the maximum strength realisable by each cotton have been estimated from the curves given in Figures 5 and 6, and are given for reference in Table VI. On correlating the hair weight per cm. with the percentage of maximum strength attained with a twist constant of 3·0, it is found that the coefficient is —0·65 for the single thread test and —0·80 for the lea test, showing that, other things being equal, fine cottons give better results than coarse cottons with low twist. The fact that the lea test results give the higher coefficient is again due to the influence of irregularity and it becomes more and more evident that in making the choice of cotton, whether from the grower's or the spinner's point of view, the chief aim should be to select one which will give a regular yarn rather than one with great fibre strength, even though by that term is implied strength per unit of weight (see p. T218). If a yarn is more regular it is automatically stronger, and it would seem as though there were more scope for improvement by attempting to decrease irregularity than in any other direction, not only in yarn quality but also in cloth quality, more especially where the latter is to be supplied to a strength specification.

Table VI

Proportion of Estimated Maximum Strength realised when Twist Constant = 3·0
Counts of Yarn 24's

	Lea Test Results Breaking Lengths			Single Thread Test Results, Breaking Lengths		
Cotton	Estimated Maximum Strength A	Strength at $3\sqrt{C}$ B	$\frac{B}{A}$ %	Estimated Maximum Strength A	Strength at $3\sqrt{C}$ B	$\frac{B}{A}$ %
A	2,230	2,081	93·7	19·2	15·07	78·6
B	2,340	2,170	92·7	18·7	17·93	94·7
C	2,250	1,935	86·0	19·3	16·25	84·4
D	2,060	1,548	75·1	18·9	13·30	70·4
E	2,250	1,963	87·3	18·6	15·83	84·9
F	2,340	1,922	82·1	20·6	16·83	81·5
G	2,220	1,886	85·7	19·3	16·02	82·9
H	2,250	2,049	91·1	17·6	16·66	94·8
I	1,990	1,673	84·0	16·7	13·74	82·0
J	1,680	737	43·8	16·2	10·37	64·2
K	2,030	1,793	88·4	17·2	14·87	86·6
L	2,060	1,239	60·1	17·5	12·35	70·8
M	2,000	509	25·4	17·2	9·88	57·6
N	1,960	1,274	65·0	17·1	12·80	74·8
O	2,150	1,380	64·2	18·0	14·18	79·3

The Relation between Yarn Strength and Hair Strength

The investigation of the relation between hair strength and yarn strength is complicated by many indeterminate factors. It may be of interest, nevertheless, to examine briefly the significance of the results obtained in the light of the previous discussion, and the treatment may most conveniently be based on the following two correlation coefficients which have been calculated—

(1) Lea breaking length 24's/4·0 and hair breaking load, $r = -0{\cdot}61$.

(2) Lea breaking length 24's/4·0 and hair breaking load÷hair weight per cm., $r = +0{\cdot}18$.

The first of these verifies the statement made by Balls[2] that "the weaker the hair the stronger the yarn." In arriving at this result, however, no correction is made for the number of hairs in the yarn cross-section. This is done in the second correlation above by introducing the hair fineness factor; but now a significant negative correlation, which will be discussed later, has been turned into an insignificant positive one, and, as other workers have already observed,[1], [2], [13] it would appear as though the specific strengths of the raw cottons (Table I, column F) have no relation at all to yarn strength. This result cannot be accepted without qualification, however, for when a yarn is tendered by exposure to light the component hairs lose strength in exactly the same proportion as the yarn does.[6]

From this it is impossible to avoid concluding that hair strength must in some way influence yarn strength, but that its effect is obscured by the operation of other factors. From what has already been said, it is evident that probably the most important of these is the yarn regularity, which has been shown to be largely determined by hair fineness, i.e. the potential hair strength can only be reflected in the yarn strength to the extent that the yarn regularity will permit it. It is therefore not surprising to find that hair fineness is closely related to yarn strength.

In the present case, the following values for correlation coefficients were obtained—

Hair weight per cm. and lea breaking length	24's/3·0	... ...	—0·82
,, ,, ,, ,,	24's/4·0	... ...	—0·70
,, ,, ,, ,,	24's/5·5	... ...	—0·44
,, ,, ,, ,,	24's/7·0	... ...	—0·46
,, ,, ,, ,,	40's/4·0	... ...	—0·79
,, ,, single thread breaking length	24's/4·0...		—0·71
,, ,, ,, ,,	40's/4·0...		—0·81

It will be observed that the fine cottons which are the superior in 24's counts are also superior in 40's, from which it follows that, at any rate within the range of counts here used, they will also spin satisfactorily to higher counts. Their superiority in this respect, however, is relatively small as is shown by Table VII, which gives the counts at which the lea breaking lengths would fall to 1800.

A further reason for the fact the hair strength is not reflected in yarn strength may be found in the manner of testing the former quantity. Hair strength is usually measured, as in the present case, over free centimetre lengths, and, as has been shown by Clegg,[4] is determined largely by the incidence of abnormalities and weak places in that length. In yarn form, on the other hand, the hairs are stressed over very much shorter free lengths, and the strong portions of one support the weak places of its neighbour, depending on such factors as the compactness of the yarn, the frictional force between the hair surfaces, and such actual interlocking as may occur. The accession of strength due to this mutual support must be determined in extent by the variability of strength in each hair. Therefore the strength of centimetre test pieces is not necessarily any measure of the hair strength contribution to yarn strength. It is quite conceivable that if the hair strengths had been tested over 1 mm. lengths, the results might have placed the 15 cottons in a very different order.

Table VII

Maximum Count Spinnable*

A ...	34·9	...	F ...	36·5	...	K ...	30·4
B ...	34·9	...	G ...	35·3	...	L ...	30·8
C ...	34·8	...	H ...	34·6	...	M ...	25·6
D ...	33·6	...	I ...	29·4	...	N ...	29·7
E ...	35·1	...	J ..	18·3	...	O ...	33·5

PRACTICAL SIGNIFICANCE OF THE CONCLUSIONS

(1) *Selection of Cottons to give best Spinning results*—The relationships indicated in the preceding pages between yarn strength and the various measurable hair properties are not sufficiently rigid to warrant their use in particular cases. For example, although in general, fine cottons are the best, the Memphis cotton O, with a hair weight per cm. of 239, gave an appreciably stronger yarn in 24's/4·0 than did the Punjab American cotton D, the hair weight per cm. of which was 182. Therefore, apart from the fact that in most cases it would not be a practical proposition to make laboratory measurements of hair properties a guide to routine purchases, it is questionable

* This is here taken as that count at which the lea breaking length = 1800, assuming a linear fall from 24's to 40's, and using Turner's method of determination.[14]

whether there would be any material advantage in doing so, except where whole crops are being bought or where the cotton concerned is a new one and unfamiliar to the graders.

In connection with the results discussed on pp. T222 and T223 an interesting point arises as to what is meant by a grader when he refers to the "strength" of a cotton. It is clear that he cannot mean merely the strength of the cotton hairs, but rather the strength of yarn they will make, otherwise his grading would be expensively misleading to the spinner. The presumption is that he builds up by constant practice and long experience a series of associations between the results obtained in yarn form and the sensations he experiences in making his pulls of the cotton sample. These sensations are not limited to the amount of effort required to break the staple, but are integrations of the effects of several hair properties such as silkiness, "life," the sound of the break, and so on.

On the other hand, something more definite may be said to the grower. In the first place, length of staple should not be regarded as the sole outward sign of a good cotton. A short but fine cotton may be capable of producing as good a yarn as a longer one, and may possibly be the more suitable for cultivation in many areas because of a greater yield of lint per acre. Secondly, hair strength can only affect yarn strength in so far as the other hair properties and their effects permit. On this account it is better to develop a fine cotton rather than one with a high hair breaking load. If the two properties can be developed in the one cotton, then, of course, so much the better. And thirdly, work already done on the hair property of fineness[10] indicates that fineness should not be achieved at the expense of wall thickness, for in that case the only result is to produce a relatively immature cotton which suffers badly in the course of mill treatment and if it does not make a neppy yarn, at least makes a poor one in other respects.

(2) *Twist Multipliers*—The multiplier of 4·0 which is commonly adopted for twist yarns from cottons of the class dealt within this work has been shown to be rather higher than that which is necessary to give the most serviceable yarn from the point of view of strength. This may be because the need for extensibility makes the greater twist necessary, but the work of Corser and Turner[5] in connection with yarn twist and cloth strength, seems to indicate the need for further research on the question.

(3) *The Conduct of Spinning Tests*—Although it has been shown that in a number of cottons the order of strength in one count is similar to that in another, yet the similarity is not so close that a spinning to one count will completely portray the industrial behaviour of a cotton when it comes to a question of particular samples. Spinning over a reasonable range of counts is necessary. In addition, there seems to be no reason for expressing the test results in terms of both lea strength and single thread strength. Neither test can be looked upon as providing an *absolute* measure, and on that score there is nothing to choose between them. There are, however, some good reasons for preferring the lea test provided that it is intelligently carried out. It is more sensitive to the presence of weak places, on account of the greater length of specimen tested; the sampling error is very much smaller than in the single thread test; it is quicker and less laborious, and, further, it is the generally accepted criterion of yarn quality in the trade.

APPENDIX I

EXPERIMENTAL DETAILS

Hair Measurements

Hair length measurements were made by means of Foster's modification[7] of the Balls' Sledge Sorter, each mean involving observations on approximately 500 hairs, taken at random, so that the probable error of the mean was of the order of 1 per cent. In addition to this error due to normal variation, there is also that due to sampling, which may be considerable. In general the length measurements cannot be regarded as accurate to less than 1 mm. The modal lengths were estimated from the frequency curves, but the accuracy of the values so obtained is less than that of the means, especially in the case of flat-topped curves.

Hair breaking loads were measured on Balls' Magazine Hair Tester under the prevailing atmospheric conditions. Mann[8] has already shown that any error thus introduced is negligible compared with that due to sampling. The number of tests made on each sample was 200, the probable error of the means being therefore approximately 2 per cent.

The hair weight per cm. determinations were carried out in the manner described by the author in a previous paper.[10]

Spinning Particulars

The rollers of the slubbing, intermediate, and roving frames were all dead weighted and the settings employed were as follows—

Slubbing—A to K, $1\frac{9}{32}$ in.; L to O, $1\frac{5}{32}$ in.

Intermediate—C, G, H, $1\frac{5}{32}$ in.; O to O, $1\frac{1}{32}$ in., others, $1\frac{1}{8}$ in.

Roving—C, H, $1\frac{5}{32}$ in.; A, B, F, G, K, $1\frac{1}{8}$ in.; I, J, $1\frac{1}{16}$ in.; D, E, $1\frac{1}{32}$ in.; L to O, 1 in.

The roving produced was 5 hank, and the twist constant used was the same for all the cottons. In order to keep within practicable limits the time taken in the preparation and spinning of the yarns, it was necessary to treat the samples simultaneously on different spindles rather than successively on the same spindle, as would have been preferable.

The last stage in the preparation at which the weight per unit length of each sample was standardised was at the finisher drawframe. After that, the only difference in the treatment given—with the one exception, referred to below—was in the matter of setting. The deviations from normal in the final yarn count can therefore be regarded as characterising the behaviour of the cottons under these conditions. On the ring frame four spindles were permanently allotted to each sample, the groups of four having previously been shown to have the same spinning efficiency within the limits of accuracy in testing. The general condition of spindles and spindle-bands was as nearly as possible perfect.

The roller settings were as follows (self weighted middle and back)—

A and C, $1\frac{1}{32}$ in.; B, 1 in.; D to H, $\frac{31}{32}$ in.; I, J, and K, $\frac{15}{16}$ in.; L to O, $\frac{7}{8}$ in.+clearance.

In order to achieve this range of setting on the same frame, the shorter cottons were spun on one side and the longer on the other, each side having appropriate bottom roller setting; the distance between nip and nip was then varied to suit each sample by altering the position of the top rollers.

The decisions as to suitable settings had to be made from hand-stapling estimates of the roving, since the hair measurements were not at that time available. Table VIII shows how the measured length properties of the cottons compared with the settings employed.

Table VIII

Roller Settings and Staple Lengths Properties

	A Roller Settings mm.	B Mean Staple mm.	C A—B	D Modal Length mm.	E A—D
A	26·2	22·7	3·5	26·0	0·2
B	25·4	22·8	2·6	24·5	0·2
C	26·2	22·0	4·2	26·0	0·2
D	24·6	20·6	4·0	20·5	4·1
E	24·6	19·8	4·8	24·0	0·6
F	24·6	23·1	1·5	26·0	−1·4
G	24·6	20·5	4·1	25·0	−0·5
H	24·6	20·8	3·8	25·6	−1·0
I	23·8	19·8	4·0	23·0	0·8
J	23·8	21·4	2·4	25·0	−1·2
K	23·8	21·0	2·8	24·0	−0·2
L	22·4	20·5	1·9	21·0	1·4
M	22·4	19·0	3·4	21·4	1·0
N	22·4	20·8	1·6	21·0	1·4
O	22·4	20·6	1·8	24·0	−1·6

It will be noticed that, with respect to mean hair length, the settings for samples B, F, J, K, L, N, and O were closer than for the others, and in particular for F, L, N, and O. With respect to the most frequent hair length, samples F, G, H, J, K, and O had settings inside that length and all the others outside.

Further modification of the normal procedure had to be adopted in certain cases. Thus, whilst ordinarily the average spindle speed was 8,000 r.p.m. it had to be reduced to 6,500 r.p.m. for spinning the 24's with a twist constant of 3·0, and with these yarn particulars the travellers had to be changed for sample M (Sircar) to one count lighter, i.e. from the normal 1/0 to 2/0 (American system).

The Testing of the Yarns

Lea Strength—The machine used was a 120 lb. capacity Goodbrand Lea Tester operated at a lower jaw speed of 12 in. per minute. Each lea, wrapped on the reel with a straight traverse, was conditioned for at least three hours and transferred to the hooks of the machine without disturbing the straight lie of the threads, in order to reduce to a minimum any random variation in the inter-thread friction during loading.[9] Four leas were tested from each of the four bobbins of each yarn, 16 tests in all, and the counts determined on a carefully calibrated and sensitive quadrant balance. Variation in count was allowed for by giving the strength as the count × lea-strength product. (Breaking length.) The atmospheric humidity was maintained at 70% R.H. and the temperature at 70° F.

Single Thread Strength—This was measured on the Moscrop Automatic machine running at the rate of six cycles per minute. Every precaution was taken to ensure a minimum of friction in the spring loaded carriages and load indicator needles, and the springs were examined for correct calibration at the beginning of each series of tests. Each result is the mean of 960 tests. Here again a correction for count was made, and the results are expressed in terms of the single thread breaking lengths in hanks. To do this, preliminary experiments were carried out to determine the length of yarn

involved per break, which was found to be 34·4 cm. By weighing the broken test-pieces at the finish of each chart, the counts could then be calculated.

Irregularity of strength, as given by the standard deviation per cent. was calculated from the single thread test results.

APPENDIX II

Theoretical Considerations of Twist in Cotton Yarns

There can be no doubt that the rise in strength of yarn with increasing twist is entirely due to the increasing binding effect making more and more of the hair strength available. Thus, with very little twist the yarn breaks entirely by hair slippage as in roving, whereas with normal turns the proportion of the number of hairs which break is quite considerable.[4]

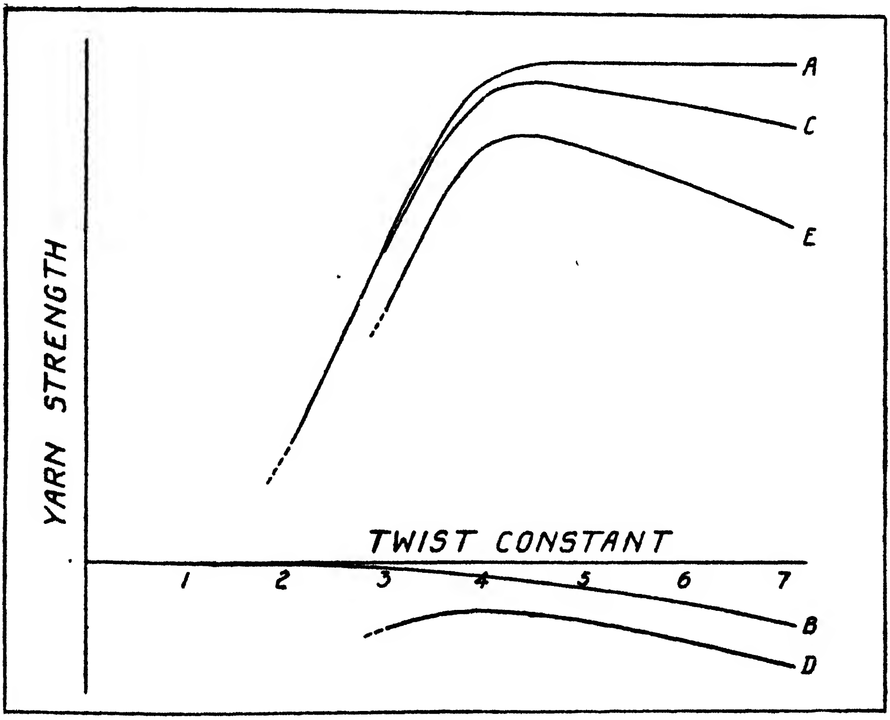

FIG. 7

The two factors which determine the effectiveness of the binding are (*a*) the pressure between hair and hair set up by the twist, and (*b*) the nature of the hair surface under which heading is also included hair convolutions. No direct observation has been made with regard to (*b*) in this work, but it is clear that it may be of considerable importance. (Cf. causes of increased irregularity in finer counts and for harder twist, pp. T211 and T212.)

The mechanism of the effect of twist on yarn strength may be represented in simple fashion by curves of the kind shown in Fig. 7. Curve A represents the amount of hair strength made available by the increase of the binding due to twist, and shows how beyond a certain point, no amount of additional twist will make any difference in this respect.

Curve B shows the stresses set up within the yarn during strain which have a shearing action because of the inclination of the hairs to the yarn axis, and which, therefore, effectively reduce the load which the yarn can stand. These two combined give curve C. Then there is to be considered the loss of strength due to irregularity, which, as may be judged from the figures given in Table II, must be very considerable. This is represented by curve D, which, when combined with curve C, gives curve E, the latter being the curve for the general effect of twist on yarn strength.

The basic component curve A is probably the most important of the three from the point of view of this work, for its peak value is governed by the maximum strength which the hairs can give when stressed in the form of an intimate group and when in the imaginary condition of a perfectly uniform yarn without twist. Unfortunately, it is impossible from the data provided to estimate its position and shape for the various cottons, for the final curve E is the only one which is definitely known, and the modifying influences of the components B and D cannot be assessed with sufficient accuracy to isolate A. The slope of this curve up to the point at which maximum binding takes place, however, will depend on hair properties other than strength, and disregarding length, will be determined by—

(*a*) The coefficient of friction of the hair surface, and possibly the disposition of the convolutions.

(*b*) The effectiveness of the contact between the hair surfaces.

(*c*) The resolved force of the tension on the yarn which acts at right-angles to the hair axes.

Of these (*a*), as has already been stated, has been outside the scope of this work; (*c*) may depend on the fineness of the hairs in so far as this may influence the yarn diameter and therefore the angle of twist for any given twist constant; (*b*) would indicate that the rigidity, and therefore the fineness,[11] of the hairs plays an important part, not only because any resistance to twisting will tend to render difficult the actual incorporation of the cotton into yarn form at the delivery of the spinning frame rollers, but also because their rigidities determine the degree to which the hairs permit themselves to be forced into contact with one another to form a compact yarn structure. As has been said, direct verification of this is impossible.

The shape of curve B will probably be determined largely by the structure of the yarn regardless of hair properties, and will be therefore much the same for all the cottons. At the same time, slight modifying influences will be brought into play by the fact that the finer cottons tend to produce a more compact yarn and consequently give a smaller angle of twist for a given twist constant.

The remaining component curve D provides interesting possibilities. In the first place, its general position with respect to the x axis will be determined by a combination effect of hair properties and spinning efficiency. Thus the greater the tendency of a cotton to produce an irregular yarn under given spinning conditions, the greater will be the loss of strength on that account, and therefore the further away from the x axis will it be in the final figure. And poor spinning will, of course, accentuate this. The shape of the curve, which is the more important from the point of view of the present discussion, will also depend to some extent on the efficiency of the spinning, but will

primarily depend on the reaction of the hairs to that spinning, and this may be responsible for the fact that certain cottons were found to be much worse than others in the extent to which they maintained their regularity with twist constants above or below 4·0, or thereabouts (p. T212).

APPENDIX III

Below is given a complete list of all correlation co-efficients which have been calculated, whether they are referred to in the foregoing text or not. Of the total correlations (Nos. 1–32), those numerically greater than 0·59 may be considered significant. For the partial correlations (Nos. 33–39), the corresponding limit is 0·61.

Hair Properties

(1) Hair breaking load and hair weight per cm. ... ... $r = +0{\cdot}53$
(2) Hair weight per cm and mean hair length ... ... $r = -0{\cdot}23$
(3) Hair weight per cm. and hair breaking load ÷ hair weight per cm. ... $r = -0{\cdot}53$
(4) Hair length irregularity and irregularity of hair breaking load ... $r = -0{\cdot}42$

Yarn Properties

(5) Single thread breaking length and irregularity of 24's/4·0 ... ... $r = -0{\cdot}49$

Hair Properties and Yarn Properties

(6) Hair weight per cm. and lea breaking lengths 24's/4·0 ... ... $r = -0{\cdot}70$
(7) Hair weight per cm and single thread breaking length 24's/4·0 ... $r = -0{\cdot}71$
(8) Hair weight per cm. and lea breaking length 24's/3·0 ... ... $r = -0{\cdot}82$
(9) Hair weight per cm and lea breaking length 24's/5·5 ... ... $r = -0{\cdot}44$
(10) Hair weight per cm and lea breaking length 24's/7·0 ... ... $r = -0{\cdot}46$
(11) Hair weight per cm. and lea breaking length 40's/4·0 ... ... $r = -0{\cdot}79$
(12) Hair weight per cm. and single thread breaking length 40's/4·0 ... $r = -0{\cdot}80$
(13) Hair breaking load and lea breaking length 24's/4·0 ... ... $r = -0{\cdot}61$
(14) Hair breaking load and single thread breaking length 24's/4·0 ... $r = -0{\cdot}42$
(15) Hair breaking load ÷ hair weight per cm. and lea breaking length 24's/4·0 ... ... $r = +0{\cdot}18$
(16) Hair bundle strength ÷ hair weight per cm. and lea breaking length 24's/4·0 ... ... $r = +0{\cdot}13$
(17) Hair breaking load ÷ hair weight per cm. and single thread breaking length 24's/4·0 ... ... $r = +0{\cdot}37$
(18) Hair breaking load ÷ hair weight per cm. and lea breaking length 24's/7·0 ... ... $r = +0{\cdot}01$
(19) Hair breaking load ÷ hair weight per cm. and single thread breaking length 24's/7·0 ... ... $r = +0{\cdot}39$
(20) Mean hair length and lea breaking length 24's/4·0 ... ... $r = +0{\cdot}39$
(21) Modal hair length and lea breaking length 24's/4·0 ... ... $r = +0{\cdot}32$
(22) Mean hair length ÷ hair weight per cm and lea breaking length 24's/4·0 ... ... $r = +0{\cdot}83$
(23) Mean hair length ÷ hair weight per cm. and single thread breaking length 24's/4·0 ... ... $r = +0{\cdot}79$
(24) Hair weight per cm. and yarn irregularity (S.D.%) 24's/4·0 ... ... $r = +0{\cdot}42$
(25) Hair weight per cm. and average irregularity of 24's/4·0, 5·5, and 7·0 $r = +0{\cdot}63$
(26) Hair weight per cm. and average irregularity of all yarns ... ... $r = +0{\cdot}64$
(27) Hair breaking load ÷ hair weight per cm and irregularity of 24's/4·0 $r = -0{\cdot}02$
(28) Hair breaking load and average irregularity of 24's/4·0, 5·5, and 7·0 $r = +0{\cdot}56$
(29) Hair weight per cm. and percentage fall in lea breaking length on increasing count from 24's to 40's ... ... $r = +0{\cdot}916$
(30) Hair weight per cm. and maximum count spinnable ... ... $r = -0{\cdot}77$
(31) Mean hair length ÷ hair weight per cm. and optimum twist constant (lea test) ... ... $r = -0{\cdot}74$
(32) Hair weight per cm. and percentage of maximum strength attained with a twist constant of 3·0—
   Lea test ... ... $r = -0{\cdot}80$
   Single thread test ... ... $r = -0{\cdot}65$

Partial Correlations

(33) Hair weight per cm. and lea breaking length of 24's/4·0 when mean hair length is constant ... ... $r = -0{\cdot}68$

(34) As No. 33 but when hair breaking load is constant ... ... $r = -0{\cdot}57$

(35) Hair breaking load, and lea breaking length of 24's/4·0 when hair weight per cm. is constant ... ... $r = -0{\cdot}40$

(36) As No. 33, but when hair breaking load÷hair weight per cm. is constant ... ... $r = -0{\cdot}74$

(37) Hair breaking load÷hair weight per cm. and lea breaking length of 24's/4·0 when hair weight per cm. is constant ... ... $r = -0{\cdot}37$

(38) Hair weight per cm., and maximum count spinnable when lea breaking length at 24's/4·0 is constant ... ... $r = -0{\cdot}63$

(39) Hair breaking load÷hair weight per cm. and single thread breaking length of 24's/4.0 when yarn irregularity is constant ... ... $r = +0{\cdot}42$

The author wishes to thank Mr. F. T. Peirce for valuable advice in the analysis of the results, and also Messrs. B. S. Schofield and C. W. Bradley, who were responsible for most of the hair and yarn testing.

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13—THE SWELLING OF CELLULOSE, AND ITS AFFINITY RELATIONS WITH AQUEOUS SOLUTIONS

PART II—ACIDIC PROPERTIES OF REGENERATED CELLULOSE ILLUSTRATED BY THE ABSORPTION OF SODIUM HYDROXIDE AND WATER FROM DILUTE SOLUTIONS, AND THE CONSEQUENT SWELLING

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INTRODUCTION AND SUMMARY

It has been shown in the former paper of this series[6] that the behaviour of cellulose in sodium hydroxide solutions of any concentration can be explained on the assumptions that alkali is taken up (*a*) to form a sodium salt according to the law of mass action, and (*b*) without chemical reaction in amount necessary to satisfy the Donnan equation of membrane equilibrium. The value $2{\cdot}0 \times 10^{-14}$ was there rather arbitrarily chosen as the ionisation constant of regenerated cellulose, since the adoption of this figure placed the calculated maximum of osmotic pressure at roughly the same alkali concentration as the observed maximum of swelling. The present paper helps to demonstrate the reality of such a constant, and fixes its value more precisely.

The earlier measurements over the technically important range of alkali concentration were not suitable for an accurate evaluation of the acidic constant of cellulose, since on the one hand the properties of the concentrated alkali solutions themselves are not yet well defined, and on the other hand the chemically combined alkali on which calculation must be based is a comparatively small fraction of the total absorbed amount determined by experiment. A more accurate estimate of the ionisation constant of cellulose is now made by confining observations to dilute solutions of sodium hydroxide—below 0·5 molal or 2%—on which precise thermodynamic measurements have already been made by other workers. The value $1{\cdot}84 \times 10^{-14}$ at 25° C. is obtained for the ionisation constant of the regenerated cellulose used, but the adoption of this in place of the rough figure assumed in the previous paper is without serious effect on the quantitative relations discussed therein.

The swelling/concentration curve for cellulose and dilute sodium hydroxide has been established, and its shape found to be in accord with the theoretical considerations of the former paper.

EXPERIMENTAL

The Absorption of Sodium Hydroxide and Water by Cellulose

For convenience of manipulation the regenerated sheet cellulose known as "Cellophane" was again chosen as the experimental material. The method was the same as that described in the previous paper, solution merely adhering to the cellulose being removed by means of dry filter papers. The alkali solutions used contained a negligible proportion of carbonate, and carbon dioxide was excluded during the experiments. The alkali taken up by the cellulose was determined by titrating with 0·01*N* HCl to *p*H 5·0, boiling to remove carbon dioxide taken up during titration, and adding more acid till *p*H 5·0 was obtained after boiling and cooling. The experimental results are given in the first four columns of Table I, the fifth column

Table I

Analysis of the System Cellulose — NaOH — H_2O

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Solution		Gel Phase									
		Per 162 Grms. of Cellulose									
Experimental											
Molality	Mole Ratio $\frac{NaOH}{H_2O}=[Na^+]$	Total Swollen Weight (Gms.)	Moles Na	Moles H_2O Absorbed from Solution $=\frac{III-(162+40IV)}{18}$	Moles H_2O Present $=W=\frac{III-(162-23IV)}{18}$	Concn. of Sodium Ion $[Na^+]_1=\frac{IV}{VI}$	Concn. of Hydroxyl Ion $[OH^-]_1=\frac{II^2}{VII}$	Concn. of Cellulose Ion $[A^-]=VII-VIII$	Concn. of Unchanged Cellulose $[HA]=1/W-A^-$	Activity Coeff. of Hydroxyl Ion γ_{OH}	Ionisation Constant of Cellulose $=\frac{IX.1.005\times10^{-14}.18}{VIII.X.XI.1,000}$
0·087	0·00157	408	0·0570	13·55	13·60	0·00420	0·00059	0·00361	0·0700	0·80	$1{\cdot}98\times10^{-14}$
		409	0·0578	13·58	13·63	0·00423	0·00058	0·00365	0·0698		2·05
0·149	0·00268	437	0·0980	15·07	15·17	0·00646	0·00111	0·00535	0·0607	0·77	1·86
		433	0·0973	14·85	14·95	0·00652	0·00110	0·00542	0·0615		1·88
0·152	0·00274	421	0·0955	14·17	14·26	0·00670	0·00112	0·00558	0·0646	0·77	1·80
0·206	0·00371	429	0·126	14·58	14·70	0·00858	0·00161	0·00697	0·0610	0·75	1·71
		422	0·127	14·18	14·29	0·00890	0·00155	0·00735	0·0627		1·82
		418	0·127	13·95	14·06	0·00904	0·00153	0·00751	0·0637		1·87
		416	0·127	13·84	13·96	0·00910	0·00152	0·00758	0·0631		1·90
		407	0·125	13·35	13·47	0·00928	0·00149	0·00779	0·0665		1·89
0·265	0·00477	367	0·143	11·06	11·20	0·01277	0·00179	0·01098	0·0782	0·73	1·94
		373	0·146	11·39	11·53	0·01265	0·00180	0·01085	0·0759		1·97
0·326	0·00587	445	0·196	15·31	15·50	0·01265	0·00273	0·00992	0·0546	0·72	1·67
		439	0·194	14·96	15·14	0·01282	0·00269	0·01013	0·0560		1·68
0·477	0·00860	403	0·253	12·83	13·07	0·01938	0·00382	0·01556	0·0609	0·70	1·73
		398	0·250	12·56	12·80	0·01952	0·00379	0·01573	0·0624		1·72
											mean $1{\cdot}84\times10^{-}$

giving the difference between the total swollen weight and the sum of the weights of sodium hydroxide and cellulose found in the gel, i.e. the amount of water taken into the cellulose system.

Discussion of the Absorption Results

The values of the moles of water absorbed (column V) are somewhat irregular, and this is attributed to variability in the resistance which the cellulose offers to the distending osmotic forces. In the dilute solutions employed the amount of water absorbed may be taken as a measure of the swelling of the material, and this depends on a balance between osmotic stress and cohesion of the cellulose. The variability of the material therefore induces a corresponding variability in the amount of water and uncombined sodium imbibed, and this is reflected in the experimental values of total sodium absorption, but on the hypothesis of the previous paper the alkali merely imbibed can be distinguished from that chemically combined; this process is carried out in the following section.

Calculation of Combined Sodium and of the Ionisation Constant of Cellulose

Equilibrium exists between the two phases—

	GEL (1)	LIQUID (2)
Cellulose HA		
Cellulose ionised	A^- and H^+	Na^+ OH^-
	Na^+ OH^-	
	H_2O	H_2O

where $A = C_6H_9O_5$

If complete ionisation of alkali and salt is assumed, and concentrations (square brackets) are expressed as mole ratios relative to water, the following stoichiometrical relation is a very close approximation.*

$$M \text{ (total swollen weight)} = W(23[Na^+]_1 + 18) + 162$$

where W is the number of moles of water present in the gel per mole (162 gm.) of cellulose. The fourth column of Table I gives $[Na^+]_1W$, the number of moles of sodium in the gel phase; the values of W now obtained from the above equation are given in column VI of the table.

The concentration of hydroxyl ion in the gel phase $[OH^-]_1$ is now determined by means of the Donnan equation

$$[Na^+]_1 \times [OH^-]_1 = [Na^+]_2^2$$

on the assumption that the activity coefficient products on both sides of the equation are equal.

The condition of electrical equivalence

$$[Na^+]_1 = [OH^-]_1 + [A^-]$$

gives $[A^-]$, the concentration of cellulose ion (column V); the concentration of undissociated acid $[HA]$ is then $1/W - [A^-]$.

The acid ionisation constant of cellulose in terms of activities (a) is given by

$$K_A = \frac{a_{H^+} \cdot a_{OH^-}}{}$$

* The exact equation is—

$$M = W(23[Na^+]_1 + 17[OH^-]_1 + 18) + 162(1 - [A^-]W) + 161[A^-]W$$
$$= W(23[Na^+]_1 + 17[OH^-]_1 + 18) + 162 - W([Na^+]_1 - [OH^-]_1)$$

but in the dilute alkali solutions under consideration $17[OH^-]_1$ has about one-tenth the value of $23[Na^+]_1$, and can be neglected in comparison with 18, and the last term, always less than 0·2, is also negligible.

which, equality of the activity coefficients of the weak acid and its anion being assumed,

$$=\alpha_{H^+}\cdot\frac{[A^-]}{[HA]}=\frac{K_w}{\gamma_{OH}[OH^-]}\cdot\frac{[A^-]}{[HA]}$$

where γ_{OH} is the activity coefficient of the hydroxyl ion and K_w the ionic product of water,[5] taken as $1{\cdot}005\times10^{-14}$. Values of γ_{OH} have been obtained from the data of Ferguson and Schluchter[2] and of Harned[8] on the assumption that the activity coefficients of cation and anion are equal. This assumption is made in the absence of trustworthy* values of the individual ionic activities, and, though quite arbitrary, probably introduces less error than merely writing γ_{OH} as unity.

The values thus obtained for the ionisation constant of cellulose are expressed in terms of mole ratios instead of the more usual concentration units of moles per litre or per 1,000 grams of water, and are converted into the latter by multiplying by 18/1,000, giving the figures in the last column of the table. The variations in the ionisation constant show no regular trend, and a mean has been taken giving the value $1{\cdot}84\times10^{-14}$ at 25° C. The irregularities are probably to be ascribed rather to variability of the cellulose than to experimental error, since the duplicates which were taken from adjacent parts of the cellulose sheet gave values in good agreement, while those taken at random (in 0·00371 mole ratio solution) diverged more widely.

It should be noted that the approximate constancy of these values obtained for the ionisation constant is not presented as proof of the reality of either the constant itself or the implied processes of ionisation and salt formation. The assumption that such processes are responsible for the observed effects is based on other evidence—notably on the successful theoretical predictions which it makes possible.[6]

The Swelling of Cellulose in Dilute Sodium Hydroxide Solutions

In the earlier paper[6] it was indicated on theoretical grounds that the osmotic pressure concentration curve for a cellulose/alkali system should be concave to the axis of alkali concentration, or that the swelling pressure should, before reaching its maximum, increase less rapidly than the concentration of the external solution. The actual swelling curve was, however, found to be convex to the concentration axis, and it rose steeply to its maximum value. This was explained on the assumption that the observed swelling is not proportional to the osmotic pressure over the range of observation, but according to the usual relation between strain and stress, beyond a certain value of the osmotic stress the swelling increases at a disproportionate rate. On the other hand, when the stress is low the strain is, in most solid systems, proportional to the stress, and in this region the swelling curve should be of the same shape as the predicted osmotic pressure curve. The osmotic stress is low in dilute alkali solutions, and hence the course of the swelling curve at low concentrations is of particular interest.

This curve cannot, however, be determined by the analytical method described, since this requires a separate specimen for each measurement, and the variability of the cellulose itself causes, in dilute solutions of alkali,

* The method whereby Dietrich and Johnson[1] arrive at the individual activity of the hydroxyl ion seems based on a misconception of the ionic strength principle of Lewis and Randall,[4] and their postulate leads to the improbable conclusion that γ_{OH} has the same value in sodium and potassium hydroxide solutions of the same concentration.

irregular swelling from specimen to specimen. The course of the swelling curve was therefore followed by observing the increase in length of strips of sheet cellulose, cut so that the length lay in the direction of maximum extension, when immersed in alkali solutions of increasing concentration. Though the numerical values of extension varied from specimen to specimen, a curve of the same shape was always obtained; Fig. 1 shows a typical example.

The curve of osmotic pressure, calculated as in the previous paper, is shown as a broken line in Fig. 1, referred to the scale on the right, the axis of abscissæ being displaced upwards to facilitate comparison of the curves.

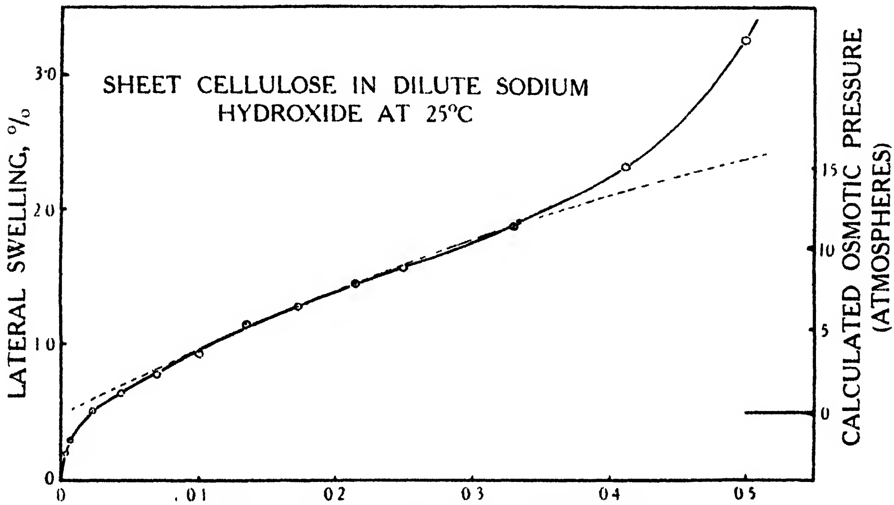

FIG. 1

The rapid early rise of the swelling curve is probably due to a small osmotic pressure, not included in the simple theory, which arises from the complete reaction with very dilute alkali of a small proportion of groups more acid than hydroxyl, probably carboxylic acid groups formed in the viscose process by the oxidation of alkali cellulose. After this early rise the curves of swelling and of calculated pressure follow closely similar courses as far as 2% extension, i.e. in the region where the strain is low and is proportional to the osmotic stress. Beyond 2% extension the swelling increases more rapidly than the pressure, just as in most solid bodies the strain quickly rises when the stress exceeds a certain value.

Where the stress is applied by external mechanical force, the phase of rapidly increasing strain is soon terminated by fracture of the solid body, owing to the localisation of stress at the ends of flaws and cracks. When a gel is distended by the action of osmotic forces, such localisation does not occur, since the stress is applied to the molecular entities themselves, and fracture now implies the more or less complete dissolution of these entities. Thus cellulose swells greatly in suitable alkaline solutions without altogether losing its rigidity, absorbing water and alkali up to 20 times its dry weight.

If the material is still further swollen, rigidity becomes less and less evident, until finally a freely flowing homogeneous solution is obtained.

Much of the experimental work was done by Mr. T. Brownsett.

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14—PHOTOMICROGRAPHS OF WOOL FIBRES: NEW METHOD

By J. Manby, F.R.P.S.
(Photographic Department, University, Leeds)

Having been struck by the apparent difficulty in obtaining a satisfactory photomicrograph of the wool fibre at a magnification great enough to show its structure, the author has attempted to solve some of the problems involved.

The chief difficulty seems to be the required depth of focus; enough to show the top scales and the edges of the fibre in focus at the one time, without the back scales, out of focus, being much in evidence. Usually the latter add greatly to the difficulty of a good photographic rendering.

The depth of focus trouble has not been overcome, but it has been found that a wool fibre can be photographed much more satisfactorily if it is mounted in a medium of suitable refractive index and viewed by suitable lighting. The fibre may be stained, which still further helps the photography, by giving more contrast.

The following is a record of the attempts which have been made to obtain a satisfactory photograph, and typical results are reproduced in the plates given at the end of the paper

EXPERIMENTAL

Mounting Mediums

Mounting mediums with differing refractive indices from air to xylol balsam were tried, and the best found was celluloid in amyl acetate, 3% solution This solution has a refractive index of 1·4049 and is of the consistency of the usual xylol balsam mountant For permanent mounts the cover-glass should be "ringed" with clear paper varnish.

Even in water or gelatin the fibre will photograph much better than in air.

Celluloid in acetone or celloidin in equal parts of absolute alcohol and ether are not so satisfactory.

No benefit has been found by photographing the fibre in a stained mounting medium, to provide a dark background (other workers say that this is not the case with transverse sections of fibres)

Staining

A differentiating counter-stain, Van Geison, used in histology, suggested itself, and although when 2% of its bulk of acetic acid was added, it gave very beautiful results visually, they did not prove so satisfactory photographically.

Acid fuchsin 5% aqueous, plus 2% acetic acid, was found to be a very suitable stain, as was picric acid, saturated aqueous solution plus 2% acetic acid A number of fibres was placed in either stain and kept at 37° C for one hour. The fibres were then washed in methylated spirit and air dried before mounting.

Illumination

Fig. (*a*), Plate I, was made by Dr. Chamberlain, and it may be considered a good average photomicrograph of a wool fibre mounted in air.

All the other photomicrographs are of fibres mounted in celluloid in amyl acetate (some fibres were also stained; see description of plates), and none was photographed by direct axial illumination.

It was found that, by using an oblique, transmitted light at right-angles to the length of the fibre, the structure was shown in a way that would photograph well.

For the one type of photohraph, Plate I, Figs. (*d*) and (*e*), Plate II, Fig. (*e*), the oblique light struck against the tips of the scales, lighting them up more than the rest of the fibre, while in the other type, Plate I, Figs. (*b*) and (*c*), Plate II, Figs. (*c*) and (*d*), the light travelled along the fibre in the same direction as the scales, and thus dark shadows or lines were produced at the tips of the scales.

It will be found that, when oblique light is used, it is much more easy to show the top scales without the under ones being too evident or confusing.

An achromatic sub-stage condenser should be used (an Abbé condenser will not stand the oblique illumination), and if this has an iris diaphragm which can be racked out of centre, then no other apparatus is necessary. If, however, the iris is fixed centrally, then some other "stop" must be used to provide the oblique illumination. A "stop" was made, Plate IV, *p* (made of white paper in the photograph, but actually of black card), which may be moved to either side of the condenser, to give oblique light from either end of the mounted fibre, which is placed in a horizontal position on the stage, at right-angles to the stop.

Dark-ground illumination may be produced by placing the stop horizontal and in the centre of the condenser, to cut out axial rays. It has been found, also, that the circular dark-ground stops (shown displaced in Plate IV, *s*), usually supplied with the microscope, may be used, and the light directed from left or right, or dark-ground illumination produced, according to how far the stop is turned into its slot in the condenser.

The light source, in this case a Pointolite, should, of course, be centred in the condenser, and in focus in the same plane as the object, i.e. the wool fibre.

The condenser iris should be as fully open as possible, preventing flare.

Vertical illumination, as used in metallography, was tried (Plate II, Fig. (*a*)), but it was given up as inferior to transmitted light for this work.

A method was tried which, at first thought, should be of real value. A fibre was stained red, lit by vertical illumination, which was screened by blue (or green) to absorb the red. In this way the fibre became opaque and it was hoped it would be easy to photograph the "surface" only, without showing the back scales. The method gave poor results.

True dark-ground illumination proved useless, Plate II, Fig. (*b*).

If a dark background should be desired, Oil Red S dissolved in the celluloid solution is useful. Basic fuchsin is insoluble in amyl acetate. Indian ink, Günther and Wagner's, as used for giving a black ground to certain micro-organisms, also gives a very suitable dark ground to the fibre, and eases the eye when studying fibres, but, as previously stated, a dark ground does not help the photography. The ink is simply used as a mountant; it does not stain the fibre.

Microscope Objectives, Plates, and Filters

An achromatic objective $\frac{1}{6}$ in. with a $\times 6$ ocular was used for all the photographs and the prints made by contact. The camera extension was 30 in. With very thick fibres it is an advantage to use a $\frac{1}{3}$ in. objective (preferably apochromatic, with which a higher power compensating ocular

may be used), and if necessary to enlarge the negative. This gives more depth of focus and in many cases the resolution would be good enough to show the structure of the fibre.

All the photographs, with the exception of Fig. (*c*), Plate II, were made on isochromatic plates, backed, with a dark green light filter (Wratten No. 56).

Fig. (*c*), Plate II, stained red with acid fuchsin, was photographed on a panchromatic plate, with an orange filter to give detail.

It is hoped that the preceding description of the methods which have been employed, together with the accompanying plates, will serve to give scientific workers a knowledge of the possible varieties of technique, from which the one best suited to their particular purposes may be selected.

Since writing this paper an attempt has been made to show the scales on a human hair by photographing by oblique light, Plate III.

DESCRIPTION OF PLATES

Merino Wool Fibres. Photomicrographs

Magnifications $\times 450$ to $\times 820$

PLATE I

(*a*) Mounted in air. All the other fibres were mounted in celluloid in amyl acetate.
(*b*) Unstained, and lit by oblique light from lower end of figure.
(*c*) Stained with picric acid, and lit by oblique light from lower end of figure.
(*d*) Unstained, and lit by oblique light from upper end of figure.
(*e*) Stained with picric acid, and lit by oblique light from upper end of figure.

PLATE II

(*a*) Stained with picric acid and photographed by vertical illumination.
(*b*) Stained with picric acid and photographed by dark-ground illumination
(*c*) Stained with acid fuchsin, lit by oblique light, and photographed on a panchromatic plate.
(*d*) Stained with picric acid and lit by oblique light from lower end of figure.
(*e*) Stained with picric acid and lit by oblique light from upper end of figure.
(*d*) and (*e*) are the same fibre and show the difference obtainable by simply moving the "stop" from one side of the sub-stage condenser to the other.

PLATE III

(*a*) Lit by oblique light from lower end of figure $\times 450$
(*b*) Lit by oblique light from lower end of figure (near tip of hair) $\times 800$.

PLATE IV

(*p*) "Stop" to provide oblique illumination.
(*s*) Dark-ground stop, also to provide either oblique or "dark-ground" illumination.

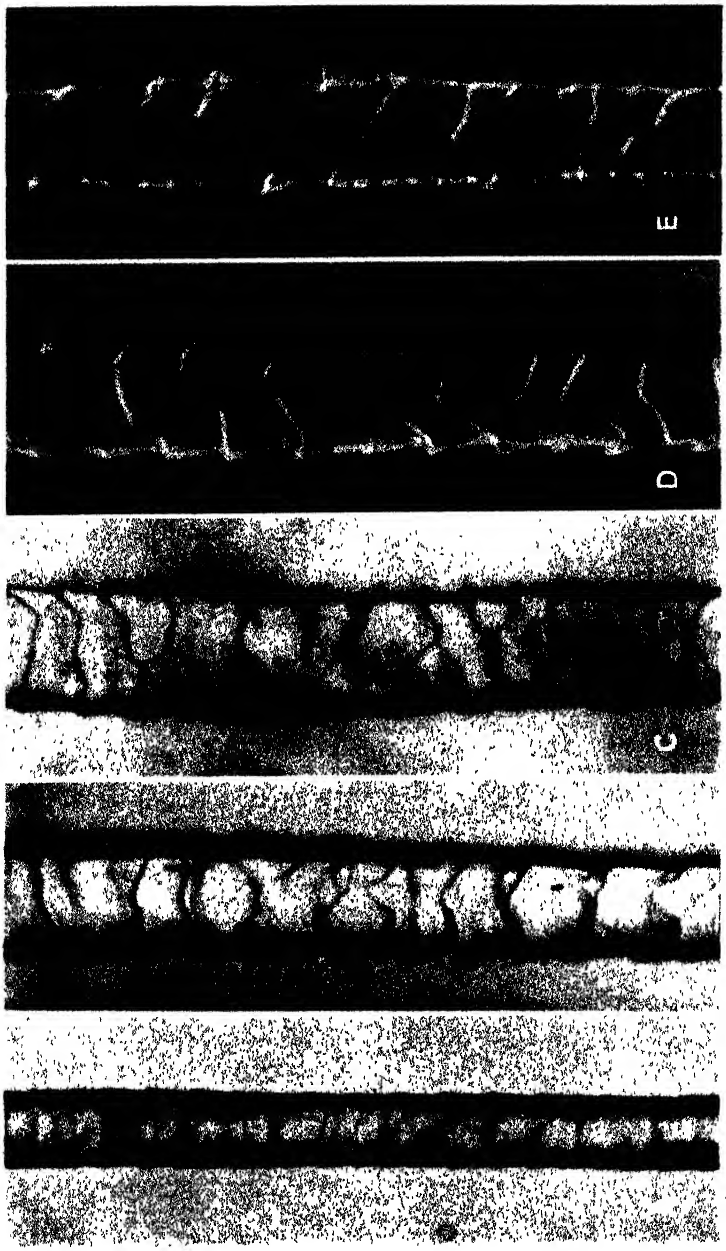

Plate I

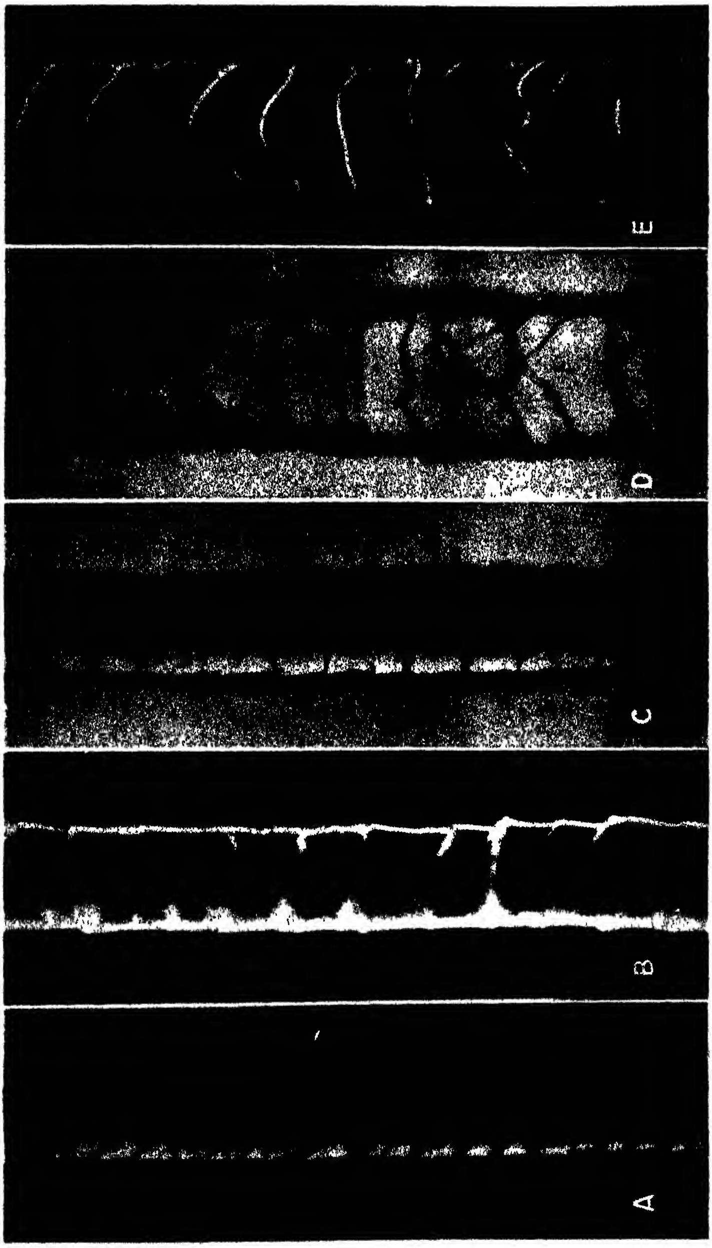

PLATE II

PLATE III

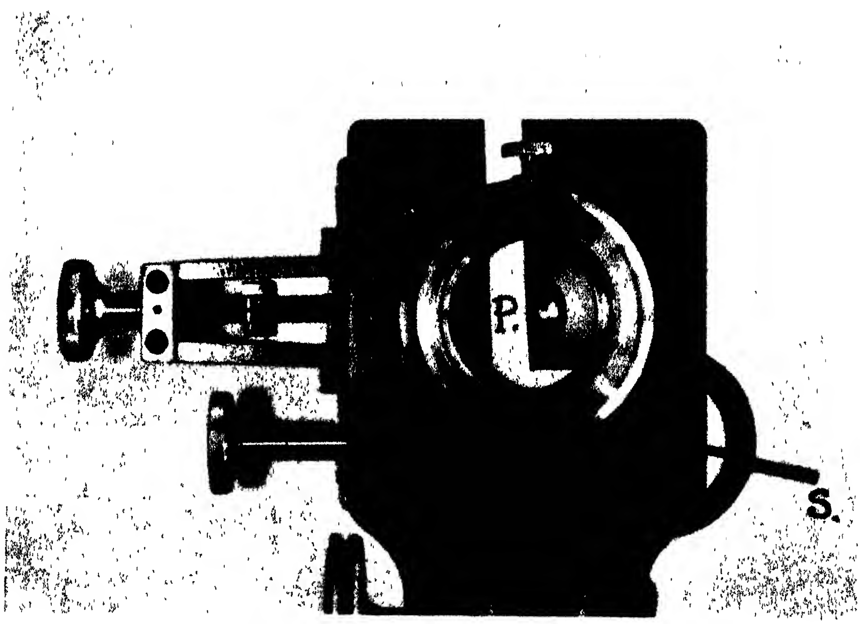

PLATE IV

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TRANSACTIONS

15—A QUANTITATIVE METHOD FOR THE DETERMINATION OF "SOUNDNESS" IN WOOL AND CLOTH

By Claude Rimington, M.A., Ph.D., A.I.C.

(From the Biochemical Department, British Research Association for the Woollen and Worsted Industries, Torridon, Headingley, Leeds)

For some time past the need has been felt for a strictly quantitative means of measuring and expressing the "soundness" of wool. "Unsoundness," when it is pronounced, can generally be detected on handling a sample of raw wool, but there is no reliable way of measuring small differences and small degrees of damage in wool, both in the loose state and in the form of cloth. The present investigation supplies such a method which is obviously capable of wide application.

Of the qualitative and semi-quantitative methods available for detecting damage in wool, that introduced by Pauly and Binz (1904), and known generally as the "Pauly test," has proved in practice to be the most suitable. Burgess (1928) has developed methods for its use both in the case of loose wool and for cloth. Damage can be detected by the reddish-brown colouration imparted to unsound fibres, the intensity affording some indication of the severity of damage.

An attempt to render the test more quantitative led to the publication by Burgess and Rimington (1929) of a method of microscopical examination in which individual fibres were examined and the extent of damage arrived at statistically. Whilst this procedure, for research purposes, is well adapted to the examination of raw wools, in the case of cloth or heavily damaged wools, its sensitivity and general applicability is less. The method to be described below utilises the "Pauly test" but differs from previous work in that the wool is so treated that a coloured solution results which can be matched in intensity against a standard dyestuff. By selecting arbitrary units, it is therefore possible to construct a scale by means of which the extent of "damage" of any given sample of wool can be expressed numerically.

GENERAL AND HISTOLOGICAL CHARACTERISTICS OF THE PAULY TEST

It was observed by Pauly (1904) that tyrosine, in common with other phenols, gives in alkaline solution a reddish-brown colouration with *p*-phenyldiazonium sulphonate, and Pauly and Binz (1904) pointed out that this reagent could be used to detect damage in wool fibres since only in those places where the epithelial scales were destroyed and the cortex of the fibre exposed did the characteristic brown stain appear.

Wool scales, free from other parts of the fibres, have never been obtained in sufficient quantity for chemical analysis, hence it is impossible to tell whether they are devoid of tyrosin or contain this amino-acid linked in such a way that its reaction with *p*-phenyldiazonium sulphonate is prevented.

The cortical protein, however, is freely reactive, and in view of the fact that mere displacement of the scales by mechanical means is sufficient to allow the brownish-red stain to develop, upon immersion of the fibre in Pauly's reagent, it would seem that the epithelium acts as a compact sheath which in a perfectly sound fibre is impenetrable, thereby preventing the cortex from becoming coloured.

Localised injuries appear as dark patches, but if treatment with the reagent is prolonged, the zone of colour broadens owing to a gradual diffusion of the reagent from the site of the lesion.

Chemical Basis of the Test

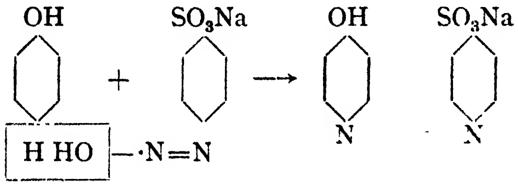
p-Phenyldiazonium sulphonate (diazotised sulphanilic acid), also known as diazobenzene-sulphonic acid, in alkaline solution, reacts with phenol or its derivatives in the following manner—

(*a*) If the para position is unoccupied, coupling takes place as in I.

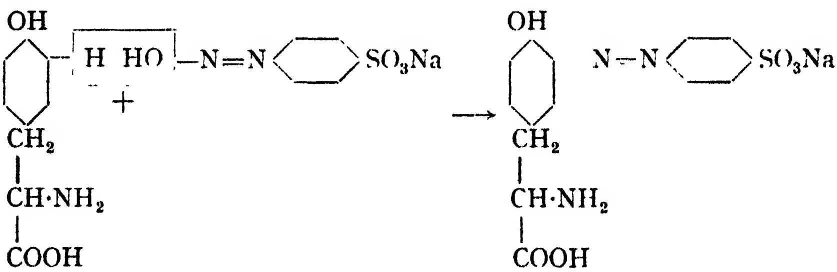
(*b*) If this position is not vacant, the coupling occurs in the ortho position relative to the hydroxyl group.

This is probably the initial stage in the reaction with tyrosine (shown in II).

I.



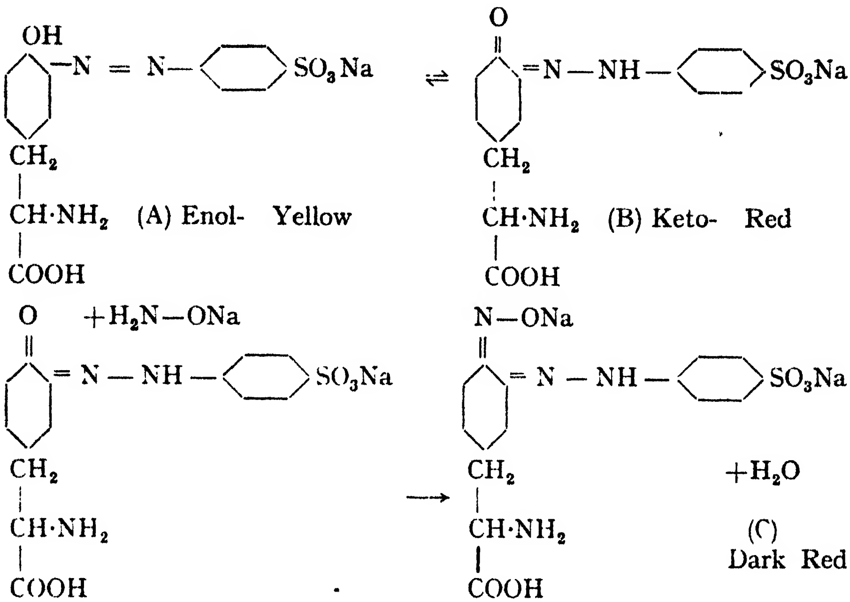
II.



The compounds so formed belong to the class of azo dyestuffs and are coloured a bright orange-red. Reaction is rapid and practically quantitative in the case of phenol; tyrosine, however, exhibits an altogether anomalous behaviour. After the addition of the reagent to a tyrosine solution, there develops an orange-pink colour which lasts for not more than a few seconds, changes sharply to yellow and fades. There is no proportionality between the final colour and the quantity of tyrosine present, hence for colorimetric purposes it is useless. Fürth (1924) finds that for maximum colour intensity the relative proportions of tyrosine and reagent are approximately 1:6, hence it is clear that secondary rearrangements and side reactions must occur, in which more reagent is used up than corresponds to the simple equation II. Hanke and Koessler (1922), who examined tyrosine, tyramine, and several para substituted phenolic compounds, such as *p*-hydroxy-phenyl lactic acid, which do not contain an amino group in the side chain, found that of all the compounds tested tyrosine and tyramine alone gave a secondary colouration with hydroxylamine hydrochloride and sodium hydroxide. This secondary colour bore a strict proportionality to the quantity of phenol

present. Hanke and Koessler consider that the reactions involved with tyrosine take place in the following manner.

Coupling first occurs as in II above; this condensation product can exist in both the enol- (A, yellow) and keto- (B, red) forms. In the presence of sodium hydroxide, the sodium phenate compound is formed, which owing to its greater degree of dissociation more readily passes into the quininoid form B. Addition of hydroxylamine gives rise to the quinoneoximehydrazone derivative (C), which in common with other compounds of its class, exhibits a deep red colour in alkaline solution.



It will be noted that Hanke and Koessler's theory of the reaction affords no explanation of the fact that it is only those phenolic derivatives containing a free amino group which behave abnormally. Since, in wool, tyrosine is combined with other amino acids, its amino group being united to them in peptide linkage -NH-CO-, and therefore excluded from interference with the diazo-coupling reaction, there seems no reason to suspect that the colour intensity developed with the reagent will deviate from true proportionality to the amount of tyrosine reacting.

It has been shown by Burgess and Rimington (1929) that in the case of wool, histidine as well as tyrosine is concerned in the reaction with *p*-phenyldiazonium sulphonate. Histidine, however, reacts smoothly and quantitatively.

As pointed out above, interaction of cortex and reagent is controlled by the condition of the epithelium, hence any method of numerical assessment of the colour intensity developed by an injured fibre affords a quantitative estimate of "soundness."

Method of Application of the Pauly Reagent and Colorimetric Determination of the Intensity of Colour Formed

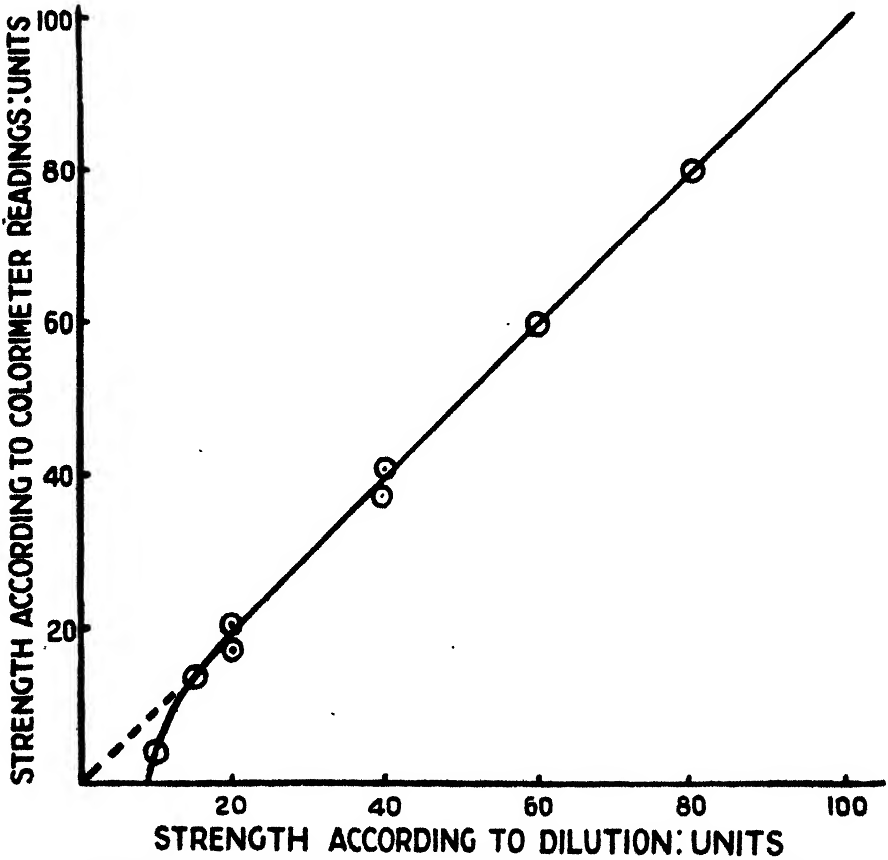
The reagent is prepared by mixing 10 c.c. of a 10% solution of sodium sulphanilate with 5 c.c. of an 8% solution of sodium nitrite, then adding 2 c.c. of concentrated hydrochloric acid down the side of the vessel, mixing with a gentle motion and allowing to stand for one minute before use.

A suitable quantity of the wool or cloth to be tested is weighed and then wetted out in 15 c.c. of a 9% solution of sodium carbonate; to this the reagent is added. After exactly 10 minutes the wool is withdrawn, rinsed thoroughly in water, and transferred to a test-tube, 4 c.c. of 10% sodium hydroxide solution is added, the tube placed in a bath of boiling water for exactly 5 minutes, and the resulting reddish solution transferred quantitatively to a graduated volumetric flask and made up to volume.

The weight of wool taken and final volume to which the solution is made depend largely upon the extent of the damage. Of cloth, a 0·1 gm. sample is convenient to take with a final solution volume of 25 c.c., but with sound loose wool 0·2 gm. may be used and the final volume made up to 5, 10, or 15 c.c.

As standard for colour comparison a 0·1% solution of "New Acid Brown S" is used. This dyestuff, in solution, has almost exactly the same tint as has the wool solution.*

The comparison may be made in a Dubosc or Kober colorimeter, and if the wool solution is pale in comparison with that of the standard, this latter may be used in a more dilute form, say, half, quarter, or even one-fifth of



Effect of dilution upon the colour intensity of a solution of treated wool.

FIG. 1

* I wish to record my thanks to Mr. H. R. Hirst for suggesting the use of this particular dyestuff, and to the British Dyestuffs Corporation (I.C.I.) for the gift of a fairly large quantity.

full strength, the appropriate correction being made when working out the numerical result.

Construction of the Numerical Scale

For convenience, it has been decided to assign the value of "100 *units of damage*" to a sample of wool (or cloth), such that 0·1 gm. treated as above and made up to 25 c.c. final volume gives a solution of colour intensity exactly equal to that of the standard dyestuff (0·1 per cent.). Values are then calculated for individual samples as may be seen from the examples worked out below.

Cloth

(*a*) Weight of sample taken 0·100 gm.
Total volume of final solution 25 c.c.
The standard dyestuff solution set at 13·7 matched the wool solution set at 20.
The number of units of damage for the sample is therefore—

$$\frac{13 \cdot 7}{20} \times 100 = 68 \cdot 5.$$

(*b*) Weight of sample taken 0·045 gm.
Total volume of final solution 10 c.c.
The standard set at 15·3 matched the wool solution set at 20.

$$\text{Therefore "damage"} = \frac{15 \cdot 3}{20} \times 100 \times \frac{10}{25} \times \frac{0 \cdot 1}{0 \cdot 045} = 68 \text{ units.}$$

Factors Influencing the Method and Proof of its Reliability

In any colorimetric method it is essential that the intensity of the colour shall fall off in a regular way with dilution and without alteration of tint. That this is true for both standard dyestuff and wool solutions (until a high order of dilution is reached) can be seen from the figures recorded below and the "dilution curve" of a wool solution shown in Fig. 1. On dilution, the colour intensity of a solution of the standard dyestuff remained strictly proportional to the concentration, and the tint was found to be unaffected.

Dilution	Colorimetric Readings: Diluted	Colorimetric Readings: Original	Colour Intensity of Diluted Solution Units	Calculated Intensity Units
Original solution ...	-	—	—	80
$\frac{3}{4}$	20	15·0	60	60
$\frac{1}{2}$	20	10·2	40·8	40
$\frac{1}{4}$	40	10·2	20·4	20
$\frac{1}{6}$	40	7·0	14·0	13·3
$\frac{1}{8}$	50	2·5	4·0	10

That the colour intensity of the final wool solution bears a strict proportionality to the weight of treated wool taken was proved in the following manner—

A sample of lightly scoured cloth (weight 7·5 gm.) was treated with Pauly reagent in the way which has been described in this paper, but using of course larger quantities of the reagents. It was assumed that damage was uniform over the whole surface of the cloth.

When dry, portions were cut off with scissors and weighed. These were dissolved in sodium hydroxide (*vide supra*), and the resulting solutions made up to a volume of 25 c.c. The intensity of each was then found by comparison with the standard dye solution.

Weight of Sample	Colour Intensity of Resulting Solution	Units of Damage
0·100	80	80
0·101	82·3	81·5
0·098	74·3	75·8
0·101	79·4	78·6
0·045	36·8	81·7
0·046	37·9	82·3
0·043	38·0	79·1

Quantity of Sodium Hydroxide Necessary to Dissolve the Wool and Time of Heating

Wide variations were made in both the strength and the quantity of the sodium hydroxide solution used for dissolving the treated wool, but the colour intensity of the final solution was not in any way affected. More prolonged heating on the water-bath does, however, lead to a reduction in intensity, therefore it was found necessary to select and define conditions of heating which would effect complete solution and give reliable comparable results. As stated above, addition to the sample of 4 c.c. of 10% sodium hydroxide solution and immersion of the test tube in *a rapidly boiling water-bath for exactly five minutes* completely fulfills these conditions.

Fading

There is no appreciable fading in the colour of the wool solution. One sample was found to have 98% of its original colour six hours after having been first prepared.

Duration of Contact with the Pauly Reagent

As noted earlier in this paper, if damaged wool fibres are left in contact with the Pauly reagent—alkaline *p*-phenyldiazonium sulphonate—one observes first of all a localised staining corresponding with the areas of injury. This is followed by a gradual broadening of the coloured zone as the reagent diffuses into the cortex. It is impossible to find a time which shall be selective of the first phase only for all fibres and all kinds of wool, but by adhering to the condition arbitrarily laid down—exactly ten minutes' immersion in the reagent—it is possible to obtain results which are strictly comparable.

Solutions Required

Sodium sulphanilate	10%	88·7 gms. sulphanilic acid dissolved in 1 litre of water containing 20·5 gms. of sodium hydroxide.
Sodium nitrite ...	8%	80 gms. dissolved in 1 litre.
Sodium carbonate ...	9%	243 gms. of the crystalline salt in 1 litre.
Sodium hydroxide ...	10%	100 gms. dissolved in water and made up to 1 litre.
"New Acid Brown S"*	0·1%	1 gm. of dyestuff dissolved in 1 litre of water and the solution filtered. Titrated by titanium chloride solution, 100 c.c. are equivalent to 0·0631 gm. iron.

Concentrated hydrochloric acid.

*Since the colour intensity, *when in aqueous solution*, of commercial dyestuffs can not be relied upon to be constant, the British Research Association for the Woollen and Worsted Industries has a large quantity of "New Acid Brown S" available. Anyone desiring to adopt the method described in this paper can obtain sufficient supplies of the dyestuff by writing to the Secretary of the Association.

Simplification of the Method for Works Practice

It is hoped that the method here recorded for the examination of wool and cloth, and the quantitative determination of its "soundness," may find application in those mills where materials and processes are scientifically controlled. For such a purpose it is not essential that an expensive colorimeter should be used. Sufficient accuracy for most purposes may be obtained by adopting the following method.

A sample of the material is taken weighing about 0·1 or 0·2 gm. (greasy wool should be washed first in benzene or ether), weighed with an accuracy of about 5%, then treated with the reagent, prepared as described earlier in this paper (p. 3) for ten minutes, rinsed with water and transferred to a test tube; 4 c.c. of sodium hydroxide solution is then added, and the tube placed in a bath of boiling water for exactly five minutes. The tube is cooled under the tap and the contents transferred to one ("Wool") of two similar, graduated measuring cylinders* marked "Standard" and "Wool" respectively. Water is added, rinsing out the test tube, to bring the volume up to 25 c.c.

In order to compare the strength of this solution with the standard (0·1% New Acid Brown), it is necessary to place the cylinders side by side on a sheet of white paper near to a window and to pour sufficient of the standard dye solution into the cylinder marked "Standard" until, when viewed from above, the colour appears identical in the two. When a match is obtained the volume of solution in the "Standard" cylinder is recorded. Suppose this is S c c., then the "damage" of the sample is calculated as follows (where W is the actual weight of wool or cloth taken)—

$$\text{"Damage"} = 100 \times \frac{S}{25} \times \frac{0{\cdot}1}{W}$$
$$= \frac{S}{W} \times 0{\cdot}4 \text{ Units.}$$

As before, "100 units" is taken as an extent of damage such that 0·1 gm. of the sample gives a solution of colour intensity exactly equal to that of the standard dyestuff.

It must be emphasised that this definition of units is purely arbitrary. It is impossible to obtain a sample of wool which one knows to be absolutely free from damage; such a sample, it is expected, would not be stained at all by Pauly's reagent, except at the cut ends; in practice, however, even a good, sound wool stains slightly, corresponding to a few units of damage. One hundred units of damage is typically represented by the state of commercial cloth (unchlorinated) which is rather below the average in soundness. Figures higher than 100 units are, of course, possible, and are frequently encountered, for example, in examining chlorinated goods.

Limitations of the Method

(1) It is not applicable to dyed or naturally coloured materials.

(2) It is difficult to obtain reliable results on materials where the degree of damage is very small. In such cases, the method of Burgess and Rimington (1929) is preferable.

The method affords an indication of the state of the epidermis of the wool fibre, which consideration is undoubtedly of paramount importance in assessing the effects likely to be produced when the wool in question is

*It is essential that these be as nearly alike as possible and have approximately the same diameter.

subjected to such processes as scouring, carbonising, etc., in which strongly reactive chemicals are used. The function of the epidermis is protective, but once a rupture or disorganisation of the latter has occurred, subsequent chemical treatment generally damages the wool to a greater extent than would otherwise have been the case.

Strength tests—always difficult to perform under conditions which shall be strictly comparable—have so far not been correlated with "damage" as determined by the present method. As explained, the present method refers to "soundness" more particularly with regard to resistance to chemical reagents and attack by micro-organisms, whilst strength tests involve, among other things, questions of the ultimate physical constitution of the fibre. In performing strength tests upon yarns and cloth, the added difficulty is encountered that twist, weave, etc., exhibit variations over the material which render any results difficult of interpretation.

In conclusion, I wish to thank Mr. R. Burgess for his helpful interest in this work.

SUMMARY

A quantitative method is described for the estimation of damage to (or "soundness" of) wool or cloth.

A weighed sample is treated with Pauly's reagent—*p*-phenyldiazonium sulphonate—prepared as described. It is then dissolved in 10% sodium hydroxide solution and the colour intensity of the resulting liquid is matched against a solution of a standard dyestuff (0·1% New Acid Brown S), using either a colorimeter or the simpler method described.

The degree of "damage" of the sample is expressed numerically—100 units of damage being a degree of unsoundness such that 0·1 gm. of the wool or cloth in question, when treated according to this method, gives a solution (25 c.c. total volume) having a colour intensity exactly equal to that of the standard dyestuff. In its simpler form the method is quite suitable for use in technical practice, mills, etc.

The mechanism of the reaction between tyrosine and Pauly's reagent is discussed from the chemical standpoint.

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16—THE INHIBITORY ACTION OF CERTAIN SUBSTANCES ON THE GROWTH OF MOULD FUNGI

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The liability of grey and, to a less extent, of finished cloths to become mildewed in a warm humid atmosphere has led to the use of antiseptics to prevent, or hinder, the growth of mould fungi. The antiseptic that has been used most widely is zinc chloride, and when present in adequate amount it has on the whole led to satisfactory results. The concentration needed to give adequate protection, however, is at least 0·8% on the total weight of the cloth, and there are many instances where this addition is either difficult or impossible, or where the use of chlorides is definitely prohibited. On this account other antiseptics have been introduced from time to time, chief amongst them sodium silicofluoride, phenol, the cresols, salicylic acid, and trichlorophenol. None of them, however, has proved a satisfactory alternative to zinc chloride.

An antiseptic suitable for general use in the cotton industry must possess most of the following properties in addition to high antiseptic efficiency.

(1) The antiseptic must not volatilise during the boiling of the size mixing or finishing paste, or the drying of the sized yarn or filled cloth.

(2) It must be sufficiently soluble to ensure uniform distribution throughout the mixing.

(3) It must be unaffected by heat, by the metallic surfaces with which it may come in contact, and by any of the ingredients commonly used in sizes and finishing pastes.

(4) The antiseptic must not have any appreciable colour or smell, and must not develop any colour at slightly acid or alkaline reactions.

(5) It must not have any action on cotton.

(6) If used in a cloth that is to be dyed or finished subsequently it must not affect these processes.

(7) To be generally useful, the cost, for equal protection, should not be greater than that of zinc chloride.

For a long time the staff of the Shirley Institute have been seeking an ideal antiseptic for use in the cotton industry to protect textile materials from fungoid attack. As little is known of any relation between chemical constitution and fungicidal properties there have been few indications to guide the search, so that substances of many types have been prepared and tested. This paper gives a summarised account of the results of the tests, and describes briefly the preparation of those substances that are either uncommon or previously unknown. The biological tests were begun by L. E. Morris and extended by one of us (L.D.G.).

In an earlier paper, Morris[27] described a method for testing the value of different substances as mildew antiseptics. This consisted in measuring the rate at which selected organisms grew on suitable sterile media containing different amounts of the substance under test. The novel feature of the method lay in the use of a number of different organisms, selected either because they occurred commonly in mildewed cloths or because they were

specially resistant to antiseptics. This practice has been continued in the present experiments, for it affords the simplest means of selecting the few substances that merit fuller examination. These have been incorporated in a range of size mixings, and their effects tested on cloths woven with the sized warps. The present memoir, however, deals only with the results obtained on nutrient media in the laboratory.

Morris[27] made a preliminary survey of the antiseptics that were either used or recommended for use in the cotton industry and also examined other substances which, either because they were used in other industries or on general grounds, appeared to be possible antiseptics. The survey revealed three antiseptics of exceptional toxicity—thallium carbonate, *p*-nitrophenol, and 2:4:6-trichlorophenol. The first of these was in many ways ideal, but there proved to be a serious objection to its general use, for the available supplies of thallium are very limited and the price is therefore so high as to make it much more expensive to use than zinc chloride. The second—*p*-nitrophenol—was both toxic and cheap, but the colour that developed in neutral or alkaline mixings precluded its general use. The third—trichlorophenol—was both pungent and volatile.

In general the investigation showed that the toxicity of phenol was increased by the introduction of alkyl, nitro, or halogen groups, whilst later experiments have shown that it is diminished by the introduction of acrylic acid, sulphonic acid, or additional hydroxyl groups, the effect of the sulphonic acid group more than counteracting that of the nitro-group.

A survey of the toxicity of the salts of different metals did not reveal any substance of outstanding merit; the search was therefore continued to find a suitable organic antiseptic.

In the first place, attention was directed to the possibility of minimising the undesirable characteristics of *p*-nitrophenol or the halogenated phenols. Acetylation of nitrophenol eliminates the colour, but the presence of acetyl *p*-nitrophenol in the requisite amount to prevent mould growth can still be detected by the colour imparted to the cloth at reactions more alkaline than *p*H6 (probably owing to hydrolysis), so that although acetylation reduced the toxicity only to one-half, the use of acetyl-*p*-nitrophenol was no more practicable than that of the parent substance. Conversion of nitrophenol into the more soluble and colourless α-glyceryl ether also failed, the ether being very much less toxic than *p*-nitrophenol. Similarly, acetylation of the halogenated phenols minimises their smell and at the same time reduces the toxicity to half, but acetyl trichlorophenol is at least as volatile as the parent substance. As with nitrophenol, the glyceryl ethers proved to be practically non-toxic.

The scope of later exploratory work is indicated in Table I. Arsenic, antimony, selenium, and thallium in organic combination proved ineffective, and although boron was more promising, it was not sufficiently so to warrant fuller investigation. The experiments led, however, to three lines of attack (*a*) acetanilide and its derivatives, (*b*) anilides of acids other than acetic acid, and (*c*) the organomercury compounds.

Acetanilide proved to be about half as toxic as phenol, and on this account its derivatives and other allied substances were investigated. The introduction of substituents into acetanilide, however, generally leads to a fall in toxicity, slight for methyl (*o* or *p*), chlorine (*p*), or nitro (*p*), and very marked for hydroxyl (*p*) or N-methyl. The toxicities of acet-β-naphthyl-

amide and 8-acetylaminoquinoline are similar to that of acetanilide, whilst acet-α-naphthylamide, 5-acetylaminoquinoline and 2-acetylaminopyridine are relatively non-toxic. One feature is perhaps worth noting. Acet-*o*-toluidide, acet-α-naphthylamide, and 5-acetylaminoquinoline, which contain a carbon substituent in *ortho* position to the acetylamino-group, are less toxic respectively than acet-*p*-toluidide, acet-β-naphthylamide, and 8-acetylaminoquinoline.

The combination of aniline with other acids led to only one substance of definite promise—salicylanilide—which is as toxic as thallium carbonate and meets the requirements for an ideal antiseptic enumerated elsewhere, save for its slight solubility. Direct sizing experiments have shown, however, that this does not prevent it from being distributed uniformly throughout a mixing or on a warp in the quantity necessary to afford efficient protection against mould growth. If it is required in a soluble form, the readily soluble sodium salt may be employed without detriment to its toxicity. Salicylanilide proved to be quite exceptional, and of other salicyl derivatives that have been prepared only the *o*-anisidide approaches it in toxicity. Replacement of aniline by *o*- or *p*-toluidine, phenylhydrazine, *p*-aminophenol, or *p*-chloroaniline reduces the toxicity to less than one-tenth, whilst replacement by methylaniline, *m*- or *p*-phenylenediamine, benzidine, α- or β-naphthylamine, *m*-aminobenzoic acid, or 5-aminosalicylic acid leads to products of very low toxicity. Similarly, replacement of salicylic acid by benzoic or *p*-hydroxybenzoic acids leads to diminished toxicity.

Introduction of mercury into the nucleus of phenol gives rise to two monosubstituted derivatives. The more soluble of these—tested in the form of *o*-chloromercuriphenol—is seven times as toxic towards mould fungi as mercuric chloride, but the less soluble *para* isomeride is only as toxic as mercuric chloride. A number of *o*-chloromercuriphenols with different substituents have been examined, but all of them are less toxic than the parent substance, the effect of the substituent in lowering the toxicity increasing in the order—

$$o\text{-Me}\ ; \rightarrow \left\{\begin{array}{l} p\text{-Me} \\ p\text{-Cl} \\ p\text{-isobutyl} \end{array}\right. \rightarrow \left\{\begin{array}{l} p\text{-isoamyl} \\ p\text{-bromo} \\ 2{:}4\text{-dibromo} \end{array}\right. \rightarrow \left\{\begin{array}{l} p\text{-nitro} \\ p\text{-sulphonic acid} \\ \end{array}\right.$$

p-Acetoxymercuriacetanilide is almost as toxic as *o*-chloromercuriphenol; the *ortho* isomeride is only one-third as toxic as the *para* whilst *o*-acetoxymercuri-*p*-toluidide is very much less toxic.

Solutions of these mercury compounds are much more stable to metals than are the inorganic mercury salts, but in boiling solution there is sufficient interaction to render them unsuitable for use in a size mixing.

The research has therefore revealed a number of substances of outstanding toxicity towards mould fungi, chief amongst them salicylanilide, *o*-chloromercuriphenol, *p*-acetoxymercuriacetanilide, thallium carbonate, *p*-nitrophenol, and trichlorophenol. Of these only salicylanilide* appears to combine a sufficient number of the desirable properties of an antiseptic for general use in the cotton industry. In view of its possible application in other spheres, it is of interest to record that solutions of salicylanilide appear to be non-toxic to plant life.

* The protection of textile and other materials from fungal attack by the use of salicylanilide is the subject of a patent; the substance is marketed by Imperial Chemical Industries Ltd. (British Dyestuffs Corporation) under their registered name "Shirlan."

EXPERIMENTAL

Part I. Biological

Method of Testing

The method of testing has been described fully by Morris[27]; the procedure need therefore be only briefly summarised.

The tests were done in sterilised media made from soft wheat flour and containing antiseptics in definite concentrations, calculated as a percentage (of anhydrous substance) on the weight of the medium. The medium usually employed was a 6% wheat flour paste, filled into test-tubes and sterilised by steaming in an autoclave on three successive days. The tubes were inoculated in duplicate with pure cultures, and incubated at 25° C. The "inhibiting concentration" is taken as that at which none of the fungi tested showed any growth in 20 days. Sometimes for further examination a 2% flour paste stiffened with 2% of agar was used. The results obtained are substantially the same as with the other medium, but the use of flour agar enables any slight retardation of growth to be more easily detected. Petri dishes containing the solidified agar medium were inverted, inoculated (each in triplicate) at the centre with pure culture, and incubated. The rate of growth was then studied by measuring at regular intervals the diameter of the circular colony that developed. The interpretation of such measurements has already been discussed.[27]

The Organisms Employed in Testing

As a result of the examination of numerous samples of mildewed cloth, yarn, and raw cotton, a collection of 180 mould fungi has been made, and, as far as possible, classified. The collection is described in the preceding memoir, and the record numbers given in the key to species in Table I are those used in that description.

The antiseptic tests were done with a number of these fungi chosen as being (*a*) types commonly occurring in cotton goods, and (*b*) the most generally resistant of such types to antiseptics. In most of the earlier tests the following species were used—*Penicillium* spp. 2 and 4; *Aspergillus flavus* 35; *A. versicolor* 45; *A. niger* 8; *Rhizopus arrhizus* 34; *Cladosporium herbarum* 15; and *Fusarium* sp. 36. Later, this selection was changed to the following as being more representative—*Aspergillus flavus* 35; *A. versicolor* 45; *A. terreus* 48; *A. fumigatus* 74; *Penicillium* sp. 85, and *Cladosporium herbarum* 15.

In addition, other common types have been substituted from time to time, and with some antiseptics a more extended range has been tried. The different mildew fungi show considerable specificity in their behaviour to antiseptics. In general, *Aspergillus flavus* 35 is the most hardy of the species tried. With organic mercury compounds, however, *Penicillium* 85 and 86 withstand concentrations several times greater than those given as the "inhibiting concentrations" in Table I. With thallium compounds *Cladosporium* is the most resistant species, and similar variations are shown with some of the other antiseptics. None of the fungi tested has proved unusually resistant to salicylanilide.

Aspergillus glaucus spp., when introduced into a test (see, for example, mercurous chloride, N-methylacetanilide, chlorinated tar phenols) have been the first suppressed.

Summary of Results

A list of the substances tested is given in Table I, together with an indication of the effect of certain concentrations on mildew fungi.

The list includes some 60 results, published and unpublished, obtained by Morris.

The inhibiting concentration has not always been determined, since the highest concentrations tested have sometimes been limited by practical difficulties, such as the slight solubility of the substance under the conditions of the test, and sometimes by technical considerations such as the cost of the substance. Three columns are therefore given, showing the concentrations corresponding to no growth, slight growth, and unrestricted growth respectively. For the sake of convenience, the fungi have been represented by letters, these and the record numbers being given in the key to species at the head of the table.

Bactericidal Action

The bactericidal properties of the substances have not been exhaustively tested. It has been observed, however, that fungicidal power and bactericidal power are not necessarily concomitant; salicylanilide and thallium carbonate, for example, are poor bactericides.

Of the less well-known substances in Table I, several are worthy of attention as possible bactericides. For example, sodium silicofluoride inhibited the development of a mixed inoculation of soil bacteria in broth in a concentration of 0·05 per cent. Diphenyliodonium chloride under similar conditions inhibited development in a concentration of 0·01% and appears to be comparable in bactericidal power with mercuric chloride.

Table I
Biological Tests on Various Antiseptics

NOTES

The most resistant species are indicated by reference letters in bold type.

Letters in brackets indicate species that are resistant to concentrations higher than those quoted as inhibiting growth.

The reference numbers are those assigned to the cultures maintained at the Shirley Institute.

* More effective the more acid the medium.

† More effective the more alkaline the medium.

‡ 0·015% has a considerable effect.

Substances described in this paper are marked thus (§). Others were made in the laboratory and a reference is given to the literature describing the method of preparation of the less well-known of them. A few rare substances were provided by other workers. The remainder were purchased from chemical manufacturers and purified when necessary.

KEY TO MOULD FUNGI EMPLOYED IN THE TESTS

	Letter	Reference No.		Letter	Reference No.
Penicillium spp.	a	2	*A. versicolor* sp.	o	60
	b	4	*A. Sydowi* sp.	p	61
	c	42	*Aspergillus fumigatus* ...	q	74
	d	68	*Aspergillus Wentii*	r	75
	e	85	*A. ruber* sp.	s	23
	f	86	*Aspergillus repens*	t	26
Aspergillus niger	g	8	*Cladosporium herbarum* ...	u	15
Aspergillus flavus	h	35	*Fusarium* spp.	v	32
A. Sydowi sp.	j	44		w	36
A. versicolor spp.	k	45	*Rhizopus arrhizus*	x	34
	l	46	*Rhizopus nigricans*	y	84
Aspergillus terreus	m	48	*Alternaria tenuis*	z	37
Aspergillus ruber sp. ...	n	55			

Table I—Biological Tests on Various Antiseptics—*cont.*

No.	Substance	% Concentration of Antiseptic: Growth inhibited	Effect marked	Effect slight or absent	Species tested
	Inorganic Compounds				
1	Alum (potassium)	—	0·5	—	e, **h**, k, m, **q**, u
2	Aluminium fluoride ...	—	0·2	—	a, b, g, h, k, l, u, w
3	Aluminium sulphate ...	—	0·36	—	e, **h**, k, m, **q**, u
4	Ammonium fluoride ...	0·04	—	—	a, b, g, h, k, l, u, w, x
5	Barium nitrate	—	0·5	—	a, b, g, h, k, l, u, w
6	Borax	0·9	—	—	a, b, g, h, k, l, u, w
7	Boric acid	—	3·0	—	a, b, c, g, h, k, u, w, x
8	Cadmium bromide‡ ...	—	0·09	—	a, **b**, g, h, **k**, l, u, w
9	Cadmium chloride‡ ...	—	0·09	—	a, **b**, g, h, **k**, l, u, w
10	Cadmium sulphate ...	—	0·09	—	a, b, g, h, k, l, u, w
11	Cerous nitrate	—	0·09	—	a, b, g, h, k, l, u, w
12	Copper chloride	—	0·1	—	a, b, g, h, k, l, u, w
13	Copper sulphate	—	0·1	—	a, b, g, h, k, l, u, w
14	Lanthanum nitrate ...	—	0·09	—	a, b, g, h, k, l, u, w
15	Lead nitrate	—	0·1	—	a, b, g, h, k, l, u, w
16	Magnesium silicofluoride ...	0·025	—	—	a, b, g, h, k, l, u, w
17	Mercuric chloride	0·02	—	—	a, b, (e), g, h, k, l, m, q, t, u, w
18	Mercurous chloride ...	—	0·03	—	a, h, k, m, q, s
19	Rubidium carbonate ...	—	1·0	—	a, b, g, h, k, l, u, w
20	Rubidium chloride ...	—	1·0	—	a, b, g, h, k, l, u, w
21	Sodium fluoride	0·8	—	—	a, g, h, u, w, x
22	Sodium silicofluoride ...	0·15	—	—	**a**, b, g, h, k, u, w, x
23	Thallium carbonate† ...	0·02	—	—	a, b, **d**, f, g, **h**, j, k, l, m, p, **u**, v, w, x, z
24	Thallium nitrate	0·02	—	—	b, h, k, u
25	Thallium sulphate	0·02	—	—	b, h, k, u
26	Thorium nitrate	—	0·09	—	e, b, g, h, k, l, u, w
27	Uranium nitrate	0·1–0·5	—	—	a, h, k, m, u
28	Zinc ammonium fluoride ...	0·1	—	—	**a**, b, g, h, u, v, x, z
29	Zinc chloride	0·8	—	—	a, b, c, d, g, h, k, m, p, u, **v**, **w**, x, z
30	Zinc hydroxide	1·0	—	—	a, b, g, h, u, v, **x**, z
31	Zinc silicofluoride	—	0·13	—	a, g, h
32	Zinc sulphate	1·0–2·0	—	—	a, b, g, h, k, u, v, w, x
	Organo-mercury Compounds				
33	*o*-Acetoxymercuriacet-anilide (§)	—	0·01	·005	e, g, h, m, q, u
34	*p*-Acetoxymercuriacet-anilide (§)	0·005	—	—	d, (e), g, h, k, m, q, u
35	2-Acetoxymercuriacet-*p*-toluidide[35]	—	—	0·01	e, h, k, m, q, u
36	Chloromercuri-*p*-bromo-phenol (§)	—	0·01	—	(e), h, k, m, q, u
37	Chloromercuricarvacrol[18] ...	—	—	0·02	(e), h, k, m, q, u
38	Chloromercuri-*o*-chloro-phenol (§)	0·01	—	—	(e), h, k, m, q, u
39	Chloromercuri-*p*-chloro-phenol (§)	0·01	—	—	(e), h, k, q, r, u
40	Chloromercuri-*o*-cresol (m.p. 183° C.) (§) ...	0·005–0·01	—	—	(e), h, k, m, q, r, u
41	Chloromercuri-*o*-cresol (m.p. 210° C.) (§) ...	0·005–0·01	—	—	(e), h, k, q, r, u
42	2-Chloromercuri-*p*-cresol*[13]	0·01	—	—	d, (e), g, h, k, m, q, u

Table I—Biological Tests on Various Antiseptics—*cont.*

No.	Substance	% Concentration of Antiseptic: Growth inhibited	Effect marked	Effect slight or absent	Species tested
	Organo-mercury Compounds—*cont.*				
43	Chloromercuri-2:4-dibromophenol (§)	—	0·01	—	(e), h, k, q, r, u
44	2-Chloromercuri-*p*-isoamylphenol[18]	—	0·01	—	(e), h, k, q, r, u
45	2-Chloromercuri-*p*-nitrophenol (§)	—	—	0·01	(e), h, k, m, q, u
46	*o*-Chloromercuriphenol (§)...	0·003	—	—	a, d, (e), (f), g, h, l, m, n, q, r, t, u, w, y
47	*p*-Chloromercuriphenol (§)...	0·01–0·02	—	—	d, (e), g, h, k, m, q, u
48	2-Chloromercuri-*p*-tert.-butylphenol[19]	0·02	—	—	(e), h, k, m, q, u
49	Dichloromercuri-*p*-chlorophenol (§)	—	0·01	—	(e), h, k, m, q, u
50	Dichloromercuriphenol-*p*-sulphonic acid (§) ...	—		0·01	(e), h, k, m, q, u
51	Chloromercuri derivatives of chlorinated low temp. tar phenols, b.p. 75–130°/3 mm. (§)	0·02		—	(e), h, k, m, q, u
52	Chloromercuri derivatives of low temp. tar phenols, b.p. 185–190° C. (§) ...	0·01–0·02	—	—	(e), h, k, m, q, u
53	Chloromercuri derivatives of low temp. tar phenols, b.p. 195–200° C. (§) ...	—	0·02	—	(e), h, k, m, q, u

Organic Compounds

The substances are arranged in alphabetical order, but terms used to indicate the position of substituent groups are not considered in the alphabetical arrangement. Metallic salts of acids and phenols are given under the acid or phenol.

No.	Substance	Growth inhibited	Effect marked	Effect slight or absent	Species tested
54	2-Acetylaminopyridine[7,38]...	—	—	0·1–0·3	e, h, k, m, q, u
55	5-Acetylaminoquinoline[8] ...	—	—	0·3	e, h, k, m, q, u
56	8-Acetylaminoquinoline[8] ...	0·3	0·1	—	e, h, k, m, q, u
57	Acetanilide	0·3	—	—	a, h, k, l, m, q, u, w
58	Acet-*α*-naphthylamide ...	—	—	0·3	e, h, k, m, q, u
59	Acet-*β*-naphthylamide ...	—	0·05–0·2	—	e, h, k, m, q, u
60	Acet-*o*-toluidide	—	0·3	—	e, h, k, m, q, u
61	Acet-*p*-toluidide	0·3	—	—	e, h, k, m, q, u
62	*p*-Acetylaminophenylstibinic acid, sodium salt[14] ...	—	—	0·02	e, g, h, k, q, u
63	Acetyl-*p*-nitrophenol* ...	0·02–0·03	—	—	a, b, g, h, k, l, u, w
64	Acetylsalicylic acid ...	0·1	0·05	—	e, h, k, m, q, u
65	Acetyltribromophenol[34] ...	0·01–0·02	—	—	e, g, h, k, q, u
66	*p*-Aminophenylarsinic acid	—	—	0·02	e, g, h, k, q, u
67	5-Aminoquinoline[8]	0·3	—	0·1	e, h, k, m, q, u
68	Benzanilide	—	—	0·1	e, h, k, m, q, u
69	Benzoic acid	0·05	—	—	a, b, g, h, k, l, o, p, u, w
70	Benzylacetamide[1]	—	—	0·1	e, h, k, m, q, u
71	*o*-Bromophenol	0·07	—	—	a, b, g, h, v, x
72	Caprylanilide	—	—	0·3	e, h, k, m, q, u
73	*p*-Chloroacetanilide ...	—	0·3	—	a, h, l, m, t, u
74	Chlorinated low temp. tar phenols, b.p. 120–165°/3 mm.	—	0·1	—	a, g, h, k, m, q, s, t

Table I—Biological Tests on Various Antiseptics—*cont.*

No.	Substance	% Concentration of Antiseptic: Growth inhibited	Effect marked	Effect slight or absent	Species tested
	Organic Compounds—*cont.*				
75	4-Chloro-*m*-cresol	0·05	—	- -	a, b, g, h, k, l, u, w
76	*o*-Chlorophenol	0·08	—		a, b, g, h, v, x
77	Chlorothymol	—	0·05	-	a, b, g, h, k, l, u, w
78	Cinnamanilide	—	—	0·3	e, h, k, m, q, u
79	Cinnamic acid	- -	0·1	0·05	e, h, k, m, q, u
80	Cresol (mixed)	0·1	-	- -	a, b, g, h, u, w
81	*m*-Cresol	0·1		—	a, g, h
82	*p*-Cresotinanilide[4]	- -	·	0·1	e, h, k, m, q, u
83	Diacet-*m*-phenylene-diamide[5]...	—	-	0·3	e, h, k, m, q, u
84	2:4 Dibromophenol... ...	0·01	—	—	a, b, g, h, u, v, x, z
85	Dichloro-*o*-cresol	0·05	—	- -	a, g, h, x
86	2:4-Dinitrophenol	0·02	—	-	a, b, g, h, k, l, u, v, w, x, z
87	Diphenyliodonium chloride[4]	- -	0·2	- - -	a, h, k, l, u, w
88	Disalicylbenzidide (§) ...	-	—	0·1	e, h, k, m, q, u
89	Disalicyl-*m*-phenylene-diamide (§)		- -	0·1	e, h, k, m, q, u
90	Disalicyl-*p*-phenylene-diamide (§)	—	—	0·1	e, h, k, m, q, u
91	Formaldehyde	0·05	—	—	a, b, g, h, u, v, x, z
92	Glyceryl-*p*-nitrophenol[6] ...	—	—	0·1	e, g, h, k, q, u
93	Glyceryl tribromophenol[24]	- -	—	0·03	d, g, h, m, q, w
94	Hexamine	—	0·5	-	a, b, g, h, k, u, v, x
95	Hexylresorcinol		0·05	- -	e, h, k, m, q, u
96	Hydrocinnamanilide ...	-	-	0·3	e, h, k, m, q, u
97	*p*-Hydroxyacetanilide ...	- -	—	0·5	e, g, h, k, q, u
98	*p*-Hydroxybenzanilide ...		·	0·1	e, h, k, m, q, u
99	*p*-Hydroxybenzoic acid ...	-	0·04	—	a, b, g, h, k, l, u, w
100	*o*-Hydroxycinnamic acid (coumaric acid)... ...	—	0·3	0·1	e, h, k, m, q, u
101	*p*-Hydroxycinnamic acid[31]	0·3	0·1	—	e, h, k, m, q, u
102	*p*-Hydroxyphenylacetic acid	—	-	0·3–0·1	e, h, k, m, q, u
103	*p*-Hydroxyphenylarsinic acid	—	-	0·02	e, g, h, k, q, u
104	N-Methylacetanilide ...	—		0·3	a, h, k, m, q, s
105	Monoacetyl-*p*-phenylene-diamine[28]	—	- -	0·3	e, h, k, m, q, u
106	Naphthalene	0·25		—	a, b, g, h, u, v, x, z
107	Naphthalene sulphonic acids and sodium salts ...	—	—	0·25	a, b, g, h, k, u, v, x
108	*p*-Nitroacetanilide		0·4	- -	a, h, k, l, u, w
109	3-Nitro-*p*-hydroxybenzoic acid	0·05–0·1	-	- -	a, b, g, h, k, l, u, w
110	*p*-Nitrophenol*	0·017	-	-	a, b, c, g, h, k, l, m, u, v, w
111	*p*-Nitrophenol-2-sulphonic acid	—	0·03	- -	a, b, g, h, k, l, u, w
112	5-Nitrosalicylic acid ...	—	0·1	—	a, b, g, h, k, l, u, w
113	Oxanilic acid	—	- -	0·1	e, h, k, m, q, u
114	Oxanilic acid, sodium salt...	—	- -	0·3	e, h, k, m, q, u
115	Phenol	0·13		—	a, b, g, h, k, l, q, t, u, v, w, x, z
116	Phenol, sodium salt ...	0·2	—	—	a, b, g, h, k, l, u, w
117	Phenol-*o*-sulphonic acid ...	—	0·3	-	a, b, g, h, k, l, u, w
118	Phenol-*p*-sulphonic acid ...	—	0·3	—	a, b, g, h, k, l, u, w
119	Phenol-*p*-sulphonic acid magnesium salt ...	—	0·3	—	a, b, g, h, k, l, u, w

Table I—Biological Tests on Various Antiseptics—*cont.*

No.	Substance	% Concentration of Antiseptic: Growth inhibited	Effect marked	Effect slight or absent	Species tested
	Organic Compounds—*cont.*				
120	Phenolsulphonic acid, mixed, copper salt	0·1	0·05	—	e, h, k, m, q, u
121	Phenolsulphonic acid, mixed, zinc salt	3·0	—	-	a, b, h, v
122	Phenylacetic acid	0·3	0·02	-	e, h, k, m, q, u
123	Phenylboric acid[26]	0·06–0·1	-	--	b, e, g, h, k, u
124	Phenylboric acid, sodium salt	0·06–0·1	--	--	b, e, g, h, k, u
125	2-Phenylglyoxaline[15]	0·3	0·1		e, h, k, m, q, u
126	Phenylpropionic acid (hydrocinnamic acid)	0·2	0·1	—	e, h, k, m, q, u
127	Phenyl salicylate (salol)	—	0·08	—	a, b, g, h, k, u, w, x
128	Phenylthiourethane		0·05	—	e, h, k, m, q, u
129	Phenylurea		—	0·4	a, h, l, m, t, u
130	Resorcinol			0·1	a, h, k, m, q, s
131	Saccharin		—	0·01–0·1	e, h, k, m, q, u
132	Salicylamide		0·1	0·05	e, h, k, m, q, u
133	Salicylyl-*m*-aminobenzoic acid (§)		—	0·1	e, h, k, m, q, u
134	N-Salicylyl-*p*-aminophenol (§)		0·2	0·1	e, h, k, m, q, u
135	N-Salicylyl-5-aminosalicylic acid (§)		—	0·1	e, h, k, m, q, u
136	Salicylanilide ("Shirlan") (§)	—	0·005	—	e, h, k, m, q, u

A 0·01% solution suppresses all but the most resistant species. Owing to the slight solubility of Shirlan, higher concentrations cannot conveniently be tested.

No.	Substance	Growth inhibited	Effect marked	Effect slight or absent	Species tested
137	Salicylanilide, sodium salt ("Shirlan S.") (§)	0·02	0·005	—	e, g, h, k, m, n, q, u, w, y
138	Salicyl-*o*-anisidide (§)		0·03	0·02	e, h, k, m, q, u
139	Salicyl-*p*-chloroanilide (§)		0·1	0·02	e, h, k, m, q, u
140	N-Salicyl-*β*-hydroxyethylanilide (§)	—	—	0·1	e, h, k, m, q, u
141	Salicylic acid	0·05	—	—	a, b, c, g, h, k, u, w, x
142	Salicylic acid, zinc salt	—	0·08	—	a, g, h, x
143	Salicyl-N-methylanilide (§)		—	0·1	e, h, k, m, q, u
144	Salicyl-*α*-naphthylamide (§)		—	0·1	e, h, k, m, q, u
145	Salicyl-*β*-naphthylamide (§)		—	0·1	e, h, k, m, q, u
146	Salicylphenylhydrazide[9]		0·02–0·1	—	e, h, k, m, q, u
147	Salicyl-*o*-toluidide[30]		0·1	0·02	e, h, k, m, q, u
148	Salicyl-*p*-toluidide[2,36]		0·1	0·02	e, h, k, m, q, u
149	Sulphosalicylic acid		—	0·1	e, h, k, m, q, u
150	Tetrabromocresol	0·03	—	—	a, b, g, h, u, v, x, z
151	Tetrahydronaphthalene	0·3	-	—	a, b, g, h, u, v, x, z
152	Thallium dimethyl iodide[16]	—	·	0·05	e, h, k, m, q, u
153	Thiocarbamide	0·8	—	—	a, g, h, x
154	Thymol	0·04	—	—	a, b, g, h, k, l, u, w
155	*p*-Toluenesulphonanilide	—	—	0·1	e, h, k, m, q, u
156	*p*-Toluenesulphonic acid, zinc salt	—	0·5	—	e, h, k, m, q, u
157	Tribromophenol	0·005–0·01	—	—	a, b, e, g, h, k, l, q, u, v, x, z
158	Tribromophenol, sodium salt	0·007	—	—	a, b, g, h, k, l, u, w
159	Trichlorophenol	0·005–0·01	—	—	a, b, g, h, k, l, u, w
160	Trichlorophenol, sodium salt	0·007	—	—	a, b, g, h, k, l, u, w
161	Trihydroxytriphenyl selenonium nitrate[26]	—	—	0·05	e, h, k, m, q, u

Part II. Chemical

Preparation of Salicyl Derivatives by Means of Salicyl Chloride

Salicyl chloride was prepared as described by Kopetschni and Karczag,[21] save that the thionyl chloride was diluted with benzene prior to mixing with sodium salicylate. Thionyl chloride (1 mol.) was mixed with twice its volume of dry benzene in a short-necked flask and treated gradually with dry sodium salicylate (1 mol.) with constant shaking and cooling. The flask was then closed with a calcium chloride drying tube and kept at room temperature overnight. The gelatinous product was thoroughly mixed with dry benzene and slowly added to a well-cooled solution or suspension of the appropriate base (2 equivalents) in dry benzene. After standing for a short time, the mixture was diluted with ether, shaken with dilute hydrochloric acid to remove unused base, washed with water, dried with anhydrous sodium sulphate, and the solvent then removed. The residue was dissolved in sodium hydroxide solution, decolorised by means of charcoal, and partly neutralised, after which carbon dioxide was passed into the solution until it was no longer alkaline to phenol red. The precipitated salicyl derivative, separated in this way from salicylic acid, was collected, washed with water, and dried.

The yield of *salicylanilide* obtained by this method was 80% of the theoretical, calculated on the sodium salicylate used; this corresponds with the yields of salicyl chloride obtained by other workers (cf. Kopetschni and Karczag,[21] and Anschütz and Riepenkroger[3]).

The interaction of the aluminium derivative of aniline with salicylic acid according to German Patent 347,607 was also investigated; the yield of salicylanilide never exceeded 9 per cent of the theoretical.

Salicylanilide dissolves very sparingly in water, 100 g. dissolving 0·005 g. at 25° C. and 0·08 g. at 100° C. It does not give any coloration with ferric chloride in aqueous solution, but alcoholic ferric chloride produces a violet colour which fades very slowly if the alcohol is free from water, but rapidly if it contains more than 2% of water.

The ***sodium*** salt crystallises from water with $4H_2O$. (Found, loss at 110° C., 23·4%; $C_{13}H_{10}O_2NNa, 4H_2O$ requires 23·5 per cent.) One hundred grams of water at 25° C. dissolve 31·7 g. of the hydrated salt. The salt is stable, for after exposure in a thin layer for a month 94% was recovered unchanged. The ***calcium and barium*** salts are both soluble in water.

Salicyl-α-naphthylamide[33] was obtained in 51% yield.

Salicyl-β-naphthylamide was obtained in 45% yield; melting point 187° C.; Senier and Shepheard[33] and Loevenitch and Loeser[22] give 188–189° C.

*Salicyl-*p*-chloroanilide* crystallises from 80% alcohol in flattened needles melting at 168–169° C. Yield, 57%; 100 g. of water dissolve 0·004 g. at 25° C. (Found—Cl, 14·3; $C_{13}H_{10}O_2NCl$ requires : Cl, 14·3 per cent.)

N-methylsalicylanilide, prepared from monomethylaniline, separates from light petroleum in clusters of stout rhombic prisms melting at 113–114° C. Yield, 72 per cent. (Found—N, 6·3; $C_{14}H_{13}O_2N$ requires : N, 6·2 per cent.) It is readily soluble in ether, benzene, or ethyl acetate, and fairly readily soluble in alcohol; 100 g. of water dissolve 0·019 g. at 25° C. Unlike N-methylacetanilide[10] it is resistant to hydrolysis by water, 85% being recovered unaltered after boiling for 4 hours.

*Salicyl-*o*-anisidide* crystallises from light petroleum in large concentric masses of needles melting at 115° C. Yield, 78 per cent. (Found—N, 5·9; $C_{14}H_{13}O_3N$ requires : N, 5·8 per cent.)

Salicyl-N-β-hydroxyethylanilide was obtained in 63% yield from β-hydroxyethylaniline. It separates from a mixture of benzene and light petroleum in glistening flattened needles melting at 100° C. It dissolves readily in ether, benzene, acetone, chloroform or ethyl acetate, but only sparingly in light petroleum. (Found—N, 5·6; $C_{15}H_{15}O_3N$ requires : N, 5·45 per cent.)

Salicylyl-5-aminosalicylic acid. No interaction appeared to take place between a suspension of the amino-acid in benzene and salicyl chloride in the cold. The mixture was therefore boiled gently for 4 hours, moisture being carefully excluded. When cold, the solid product of the reaction was washed with dilute hydrochloric acid to remove unchanged amino-acid, dried, and finally washed well with ether. Yield, 20 per cent. The substance blackens slowly when heated and decomposes at about 270° C.; it dissolved so sparingly in all the usual solvents that all attempts at crystallisation were unsuccessful. (Found—N, 5·1; $C_{14}H_{11}O_5N$ requires : N, 5·1 per cent.)

Salicyl Derivatives Prepared by Means of Salol

This method was first described by Cohn[9] and gives almost a theoretical yield of salicylanilide.

*Salicylyl-*p*-aminophenol* (*p*-hydroxysalicylanilide) was prepared by heating a mixture of salol (1 mol.) and *p*-aminophenol (1·1 mol.) dissolved in phenol in an oil bath at 200° C. for 4 hours. After crystallisation first from aqueous alcohol and then from boiling water it melted at 176° C. (Cohn[9] gives 168–169°). (Found—N, 6·2; $C_{13}H_{11}O_3N$ requires : N, 6·1 per cent.)

*Salicylyl-*m*-aminobenzoic acid.* *m*-Aminobenzoic was dissolved in molten salol and heated at 180° C. for 1 hour, during which time the product gradually crystallised. When cold, the mass was broken up and washed thoroughly with ether. Yield, 85 per cent. It is extremely insoluble in all the usual solvents with the exception of acetone, from which it separates very slowly in microcrystalline nodules decomposing at 275° C. (Found—N, 5·7; $C_{14}H_{11}O_4N$ requires : N, 5·45 per cent.)

*Disalicyl-*m*-phenylenediamide.* Freshly distilled *m*-phenylenediamine (1 mol.) was heated with salol (2 mols.) at 185° C. for 2½ hours in an atmosphere of hydrogen. The ethereal solution of the product was washed with dilute hydrochloric acid and with water, dried, and the ether evaporated. The residue separated from alcohol in concentric clusters of stout prisms melting at 200° C. (Found—N, 8·1; $C_{20}H_{16}O_4N_2$ requires : N, 8·05 per cent.) It dissolves sparingly in ether, fairly readily in alcohol or ethyl acetate, and very readily in acetone; it is almost insoluble in benzene, light petroleum, or chloroform.

*Disalicyl-*p*-phenylenediamide* was prepared in the same way as the *meta* isomeride. The crude solid product was purified by washing thoroughly with ether. It is almost insoluble in the usual solvents but dissolves in hot pyridine, from which it separates in glistening needles containing solvent of crystallisation, which is rapidly lost on standing in the air or in a vacuum. (Found—N, 8·25; $C_{20}H_{16}O_4N_2$ requires : N, 8·05 per cent.)

Disalicylbenzidide was prepared in the same way as disalicyl-*p*-phenylenediamide. It is extremely insoluble in most solvents, but separates from pyridine in small glistening leaflets, which change to a powder in contact with the air or in a vacuum. (Found—N, 6·6; $C_{26}H_{20}O_4N_2$ requires : N, 6·6 per cent.) The preparation is briefly described by Cohn[9], but no analyses are recorded.

Mercury Derivatives of Phenols

The mono-mercuration of phenol. By the interaction of phenol and mercuric oxide in equimolecular proportions in acetic acid, Dimroth[12] obtained a mixture of products consisting principally of dimercury compounds of phenol, *o*-acetoxymercuriphenol accounting for only 15% of the mercuric oxide and *p*-acetoxymercuriphenol for 6 per cent. More recently, Whitmore and Middleton[38] and Mameli[23] have stated that the *gradual* addition of mercuric acetate (1 mol.) to phenol (1·5 mol.) heated on a boiling water-bath leads essentially to monomercurated derivatives. The former writers also state that the relative proportions of the two isomerides at different temperatures are as follows—

Temperature		*Ortho*		*Para*
100° C.	...	28%	...	72%
125° C.	...	33%	...	66%
150° C.	...	36%	...	64%

Mameli states that at 90–100° C. 82% of the mercuric acetate is converted into mono-mercury compounds, the relative proportions of *ortho* and *para* being 37% and 63 per cent.

Using these conditions, only 18% of the mercury was obtained in the form of mono-mercury compounds, the proportion of *ortho* to *para* being 43 to 57. Further investigation showed that the maximum yield of mono-mercurated phenols was obtained by adding the finely powdered mercuric acetate *in one operation* to the heated phenol. In this way, the following results were obtained—

Temp.	Mols. Phenol to 1 mol. $HgAc_2$	Total Yield of Mono-mercurated Phenols on $HgAc_2$	Relative Proportions	
			ortho	*para*
90° C.	1·5	71%	43	57
90° C.	2	82%	42	58
60° C.	3	88%	45	55
90° C.	3	88%	54	46
120° C.	3	83%	66	34
150° C.	3	76%	81	19

Mercuration of p-*cresol.* Mercuration of *p*-cresol (1·5 or 3 mols.) at temperatures of 60° C. to 120° C. with mercuric acetate (1 mol.) led to practically the same result throughout, 25% of the mercury being isolated as *o*-chloromercuri-*p*-cresol, and 70% as 2:6-*dichloromercuri*-p-*cresol.* This is practically insoluble in water, alcohol, acetone, benzene, or chloroform, and very sparingly soluble in boiling tetrahydronaphthalene or cyclohexanol, from which it separates in clusters of minute needles, which gradually decompose without melting above 210° C.; 100 g. water dissolve 0·001 g. at 25° C. (Found—Hg, 65·0; $C_7H_6OCl_2Hg_2$ requires : Hg, 69·3 per cent.)

Mercuration of m-*cresol.* *m*-Cresol was mercurated in the same way as phenol. The mono-mercury derivatives were isolated by dissolving the reaction product in water containing a little acetic acid, adding sodium chloride, and then cooling to 50° C., filtering off the small amount of solid chlorides that separated, and then cooling rapidly and collecting the chlorides that finally separated as a mixture of crystals and oil. This material was fractionally crystallised from benzene, yielding in the more insoluble fractions a *monochloromercuri*-m-*cresol* as radiating clusters of long glistening needles, which, when heated slowly, decomposed about 230° C. without melting.

The portion more readily soluble in benzene was purified by crystallisation from chloroform, in which the solubility of the two isomerides is reversed, yielding long needles that gradually changed to a sandy powder when left in contact with the solvent. When slowly heated they softened a little at 130–140° C. and decomposed above 230° C. without melting.

Mercuration of p-*chlorophenol.* Redistilled *p*-chlorophenol was mercurated in the same way as phenol. The product was dissolved in boiling dilute acetic acid and treated with an excess of sodium chloride. The chlorides that separated were collected, dried, and separated into two fractions by means of cold acetone, which dissolved 80% of the material. The portion soluble in cold acetone, *monochloromercuri*-p-*chlorophenol*, separated from aqueous alcohol as a mass of long curved needles or as compact aggregates of short needles according to the rate of cooling and the concentration of the solution. Both forms melted at 202–203° C. It is readily soluble in acetone and in alcohol, and fairly soluble in hot water; 100 g. of water dissolve 0·032 g. at 25° C. (Found—Hg, 55·3; $C_6H_4OCl_2Hg$ requires : Hg, 55·1 per cent.) The portion that did not dissolve in cold acetone, *dichloromercuri*-p-*chlorophenol*, separated from ethyl acetate in glistening leaflets or needles melting at 245–248° C.; 100 g. water dissolved 0·001 g. at 25° C. It was decomposed with difficulty by permanganate. (Found—Hg, 62·7; $C_6H_3OCl_3Hg_2$ requires : Hg, 67·0 per cent.)

Mercuration of p-*bromophenol.* The mixed chlorides were prepared and separated as described for *p*-chlorophenol; 70% of the products dissolved in cold acetone, the remainder being practically insoluble even in the boiling solvent.

Monochlormercuri-p-*bromophenol.* The fraction soluble in acetone was crystallised repeatedly from aqueous alcohol, from which it separates in feathery clusters of short needles, melting and decomposing at 220° C. It is readily soluble in acetone, ether, or ethyl acetate, fairly soluble in alcohol, slightly soluble in boiling water, and almost insoluble in benzene, chloroform, or light petroleum; 100 g. of water dissolve 0·012 g. at 25° C. (Found—Hg, 48·7; $C_6H_4OClBrHg$ requires : Hg, 49·1 per cent.)

Dichloromercuri-p-*bromophenol* was isolated by crystallising the fraction insoluble in acetone from ethyl acetate, from which it separates in small needles decomposing at 275–282° C. according to the rate of heating; 100 g. of water at 25° C. dissolve 0·002 g. (Found—Hg, 59·8; $C_6H_3OCl_2BrHg_2$ requires : Hg, 62·3 per cent.)

Mercuration of 2:4-dibromophenol. Mercuric acetate (1 mol.) dissolved in 50% alcohol containing a little acetic acid was added to 2:4 dibromophenol (1 mol.) dissolved in the same solvent. The yellow precipitate immediately formed became almost white after heating on the steam bath for 12 hours. It consists of *acetoxymercuri-2:4-dibromophenol*, which separates from 75% acetic acid in radiating clusters of long needles that gradually decompose above 260° C. (Found—Hg, 39·0; $C_8H_6O_3Br_2Hg$ requires : Hg, 39·2 per cent.)

Chloromercuri-2:4-dibromophenol is insoluble in cold and only slightly soluble in boiling water, but fairly soluble in alcohol or hot benzene, from which it separates in large aggregates of very fine needles, that melt at 240° C. (Found—Hg, 41·3; $C_6H_3OClBr_2Hg$ requires : Hg, 41·1 per cent.)

Mercuration of p-*nitrophenol.* The process used was that described by Hodgson[30] for the mercuration of *o*-nitrophenol, with the exception that two

molecules of the phenol were used instead of a large excess. The unchanged *p*-nitrophenol was removed by thorough washing with dilute acetic acid, and the residue was crystallised from 90% acetic acid. (Found—Hg, 50·6; $C_8H_7O_5NHg$ requires : Hg, 50·4 per cent.) The monoacetoxymercuri-*p*-nitrophenol was converted into the sodium salt of hydroxymercuri-*p*-nitrophenol, which was crystallised from hot water containing a slight excess of sodium hydroxide. (Found, in air-dry material—Hg, 48·4; loss at 110° C., 8·3; $C_6H_4O_4NNaHg,2H_2O$ requires : Hg, 48·4; H_2O, 8·7 per cent.) Hantzsch and Auld[17] state that the sodium salt crystallises with $\frac{1}{2}$ H_2O. Monochloromercuri-*p*-nitrophenol was prepared from the above sodium salt by treating the warm solution with dilute hydrochloric acid. The precipitated chloride was crystallised from boiling water containing a little hydrochloric acid, and formed a voluminous mass of almost colourless needles, which darken and decompose indefinitely at about 245° C. (Found—Hg, 52·4; $C_6H_4O_3NClHg$ requires : Hg, 53·6 per cent.) Hantzsch and Auld[17] give the melting point of *o*-chloromercuri-*p*-nitrophenol as 175° C., whilst Raiziss and Proskouriakoff[32] do not record a melting point. One hundred grams of water dissolve 0·018 g. at 25° C.

*Mercuration of magnesium phenol-*p*-sulphonate.* One molecular proportion of the salt [$(OH{\cdot}C_6H_4{\cdot}SO_3)_2Mg,8H_2O$] was mercurated by slightly less than two molecular proportions of mercuric acetate in boiling alcohol containing a little acetic acid. A yellow precipitate began to form almost immediately. After boiling for about an hour it became white, and the solution gave no test for mercury ions. The solid was collected, ground in a mortar with a little concentrated hydrochloric acid, diluted with water and filtered. *Dichloromercuriphenol-*p*-sulphonic acid* so obtained formed a mass of minute leaflets, which separated from boiling water in fine glistening needles. (Found—Hg, 53·9; loss at 110° C., 9·7%; $C_6H_4O_4Cl_2SHg_2,4H_2O$ requires : Hg, 56·0; H_2O, 10·1 per cent.)

*Mercuration of *o*-chlorophenol.* The mercuration and conversion of the products into chlorides was carried out as for *p*-chlorophenol. These proved to dissolve almost completely in cold acetone; fractional crystallisation from benzene and from alcohol revealed the presence of only one *chloromercuri-o-chlorophenol.* This dissolved readily in acetone or ethyl acetate, fairly readily in alcohol or hot benzene, and sparingly in boiling light petroleum or chloroform. It separated from alcohol as a mass of fine needles, which melted at 185–186° C. without decomposition; 100 g. of water dissolved 0·01 g. at 25° C. (Found—Hg, 55·6; $C_6H_4OCl_2Hg$ requires : Hg, 55·2 per cent.)

*Mercuration of *o*-cresol.* The *o*-cresol (3 mols.) was heated at 95° C. and finely powdered mercuric acetate (1 mol.) was added with stirring; the heating was continued for 30 minutes, the product was dissolved in boiling 10% acetic acid, and the mixed mercurichlorides were precipitated by means of sodium chloride. Partial separation was effected by means of warm alcohol, which dissolved the greater part; the residue, probably *dichloromercuri-o-cresol,* was insoluble in the usual solvents and did not melt at 290° C. The chlorides that dissolved in alcohol were fractionally crystallised from chloroform, and yielded two *chloromercuri-o-cresols.* The less soluble in chloroform was crystallised repeatedly from benzene, a mixture of benzene and ethyl acetate and finally from alcohol, and then melted constantly at 210° C. (decomp.). (Found—Hg, 57·8; C_7H_7OClHg requires : Hg, 58·4 per cent.) It dissolved readily in acetone or ethyl acetate, fairly readily in hot alcohol.

but sparingly in chloroform, benzene, or light petroleum; 100 g. of water dissolved 0·014 g. at 25° C. The *chloromercuri-o-cresol* that was more readily soluble in chloroform separated from this solvent in elongated plates and from aqueous alcohol in long slender needles, which decomposed to a red liquid at 183° C. (Found—Hg, 58·8; C_7H_7OClHg requires : Hg, 58·4 per cent.) One hundred grams of water dissolved 0·019 g. at 25° C.

Mercuration of Aniline and *p*-Toluidine

p-*Acetoxymercuriacetanilide* was prepared by the mercuration of aniline and subsequent acetylation of the less soluble portion of the product as described by Dimroth.[12] It melted at 224–225° C., whereas Dimroth gives the m.p. as 220–221° C.; 100 g. of water dissolve 0·142 g. at 25° C. On prolonged boiling with water, acetic acid is split off and a fairly readily soluble base formed, which separates as a somewhat oily mass on concentration and cooling; it is readily reconverted to the original substance on treatment with acetic acid.

o-*Acetoxymercuriacetanilide* was prepared by mercuration of acetanilide in boiling aqueous solution as described by Pesci[29] who, however, isolated only *p*-acetoxymercuriacetanilide (Dimroth[12]). The crude *p*-acetoxymercuriacetanilide that separated on cooling was removed, the filtrate shaken with ether to remove unchanged acetanilide, evaporated to dryness, and the residue crystallised from ethyl acetate. o-*Acetoxymercuriacetanilide* melts at 163° C.; Dimroth,[12] who obtained it by acetylation of *o*-acetoxymercurianiline, gives the m.p. as 156–158° C. (Found—Hg, 51·2%; $C_{10}H_{11}O_3NHg$ requires : Hg, 50·9 per cent.) It is fairly readily soluble in water, but on prolonged boiling behaves similarly to the *para* isomeride, yielding a base that is readily reconverted into the acetoxy compound on treatment with acetic acid.

2-*Acetoxymercuriacet*-p-*toluidide*, prepared as described by Vecchiotti[35], melted at 179° C. (corr.); Vecchiotti gives m.p. 175° C. It was recovered unaltered after boiling for five hours with water.

The method described by White[37] has been used to determine mercury in the organo-mercury compounds. It gives excellent results with all of the mono-mercurated compounds, but is much less reliable with the dimercurated compounds which have been examined, principally owing to the difficulty of decomposing these completely with the mixture of permanganate and sulphuric acid recommended.

The authors thanks are due to Dr. T. A. Henry, for samples of the mercury compounds of carvacrol, *p-tert*-butylphenol and *p-iso*-amylphenol, to Prof. T. M. Lowry, F.R.S., for the thallium dimethyl iodide, to Prof. G. T. Morgan, F.R.S., of the National Chemical Laboratory, for the specimens of phenols from the low temperature carbonisation of coal and their chlorinated products, and to Mr. E. Moss for assistance in the preparation and analysis of many of the substances that have been tested.

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17—THE DETERMINATION OF THE VISCOSITY OF CUPRAMMONIUM SOLUTIONS OF CELLULOSE

By J. Tankard, B.Sc., A.T.I., and J. Graham

INTRODUCTION

The value of a measurement of the viscosity of a solution of cotton in cuprammonium as an indication of chemical damage has been increasingly recognised during the last few years, and a number of suggestions have been made for improving the technique of the determination so as to enable an accurate value to be obtained by a method which is sufficiently simple and rapid for industrial purposes.

Summary of Previous Methods

The methods employed for the determination of the viscosity of cellulose solutions may be divided into two groups, viz. those depending on the measurement of the rate of flow of the solution through a capillary tube, and those in which the rate of fall of a sphere through the solution is measured.

The "rate of flow" method was employed by Ost,[1] who was the pioneer in regard to work on the measurement of the viscosity of cellulose solutions, and improved by Clibbens and Geake.[2] Gibson and Jacobs[3] were the first to employ the "falling sphere" method, which was adopted by Gibson,

Spencer and McCall,[4] and improvements have since been made in this method by Joyner,[5] and by Farrow and Neale.[6]

The earlier methods of determination by "rate of flow" were open to the objection that the solution was prepared in a separate vessel from that in which the determination was made. Elaborate precautions were therefore necessary to minimise or prevent the access of air to the solution during transference to the viscometer. Again, the volume of solution which it was necessary to prepare was considerably greater than that actually employed for the determination. Clibbens and Geake[2] overcame these difficulties by preparing the cuprammonium solution of cotton in the viscometer itself. The apparatus is not entirely satisfactory, since the method of closure of the tube does not ensure that the volume of cuprammonium solution used shall be constant for any one tube in all experiments. The method also has the drawback that only one determination can be made on each solution.

The "rate of flow" method is also open to the following objections—

(1) Each viscometer must be standardised for rate of flow with a liquid of known viscosity in order to determine the constant of the tube.
(2) The capillary may easily become clogged with foreign matter.
(3) Corrections must be applied for surface tension effects and kinetic energy in order to obtain an accurate result. The latter correction varies with the viscosity of the solution under examination.

The methods so far proposed for the determination of viscosity by the "falling sphere" method are also open to the objection that the solution is prepared in a separate vessel, involving the precautions referred to above. Gibson and Jacobs,[3] Joyner,[5] and Farrow and Neale[6] employed steel spheres $\frac{1}{16}$ in. in diameter, in a viscometer having an internal diameter of 1 cm. Gibson and Jacobs[3] proved experimentally that Ladenburg's correction for wall effect did not apply under these conditions, and it was therefore necessary to standardise each tube by determining the time of fall of a sphere through a liquid of known viscosity. In order to extend the range over which accurate results may be obtained, and to improve visibility, Small[7] has introduced the use of glass spheres, 0·33 cm. in diameter in a tube of 1·5 cm. diameter. The use of glass spheres has also been recommended by the Committee on the Viscosity of Cellulose, Division of Cellulose Chemistry, American Chemical Society.[8] Here again, the dimensions are such that Ladenburg's correction cannot be applied.

Outline of Proposed Modifications and their Advantages

The method of determination which is now proposed is an attempt to minimise the objections enumerated above. The general method of procedure (detailed in Section 2) is as follows—The rate of fall of steel spheres, $\frac{1}{32}$ in. in diameter, through the cuprammonium solution is determined, the the solution being prepared in the actual tube in which the measurement is made.

The use of spheres $\frac{1}{32}$ in. in diameter (instead of $\frac{1}{16}$ in. as in previous methods) has the following advantages—

(1) Accurate determination of viscosity can be made over a wide range (as low as 1·4 log. viscosity if 2% solutions are used).
(2) Ladenburg's correction for wall effect is applicable, thus obviating the necessity of calibration of each tube.
(3) Small variations in the diameter of the tube (±0·1 cm.) do not appreciably affect the calculations of wall effect, so that it is possible

to plot a graph of Observed time of fall/Log. viscosity of solution, which applies to all tubes having a diameter of approximately 1·0 cm.

Other advantages of the method are—

(4) Although a very small quantity of cotton is required (owing to the fact that the solution is prepared in the actual tube in which the measurement is made), duplicate readings can be made on each solution.

(5) The new pattern of stopper which is used to close the open end of the tube ensures that the volume of solution for any one tube is constant in all experiments.

The determinations of viscosity can be carried out rapidly, and the method is particularly suitable for use in the control of industrial operations.

EXPERIMENTAL DETAILS OF PROPOSED METHOD OF DETERMINATION OF VISCOSITY

Preparation of Cuprammonium Solution

The solution contains 15 g. of copper and 240 g. of ammonia per litre and has a nitrite content of not more than 0·5 g. nitrous acid per litre. The method of preparation is similar in principle to that employed by Clibbens and Geake.[3] The bottle in which the cuprammonium is stored is enclosed in a light-tight box, and is provided with a suitable delivery tube at the bottom and connected at the top with a gasholder containing nitrogen.

Preparation of Solution of Cotton in Cuprammonium

The tube used consists of a piece of glass tube 28 cms. in length and of 1 cm. internal diameter, one end being closed, and the other provided with a small lip. The open end of the tube can be closed by means of the specially designed stopper shown in Fig. 1 (A.) Two marks exactly 15 cms. apart are

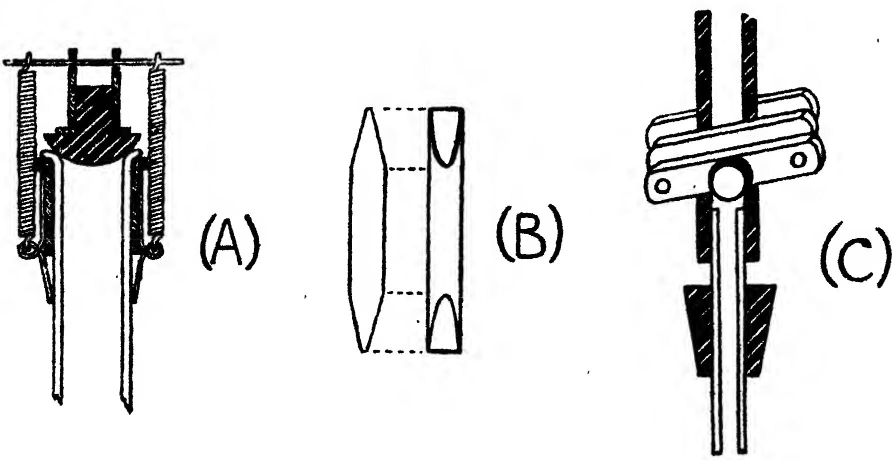

FIG. 1

etched on the tube, the lower mark being 5 cms. from the closed end. The tube is provided with a weight made from a piece of round steel rod, 4 cms. in length and 0·55 cm. diameter, tapered at each end—Fig. 1 (B). In order that the weights shall be interchangeable they are adjusted so that the variation between them is not greater than 0·01 g.

The tube is standardised for volume with a weight in the tube, and the weight of cotton required to give a solution of definite strength (usually 1% dry cotton) calculated. The moisture in the cotton is taken as 7%, i.e. 1·075 g. of the sample are taken for every gram of dry cotton required in solution, the samples being conditioned before use by exposure to an atmosphere of 70% relative humidity. This can be done conveniently by placing the sample in a closed vessel over a saturated solution of strontium nitrate at 20° C.

In the actual preparation of the solution, the required amount of cotton, in the form of short lengths of yarn (obtained in the case of fabrics by separating the warp and weft of the fabric thread by thread), is introduced so as to lie loosely along the lower half of the tube. In the case of badly tendered fabrics a 2% solution is prepared, and it is preferable to cut up the fabric into small pieces instead of separating into yarn form. A rubber stopper, through which passes a piece of glass tubing carrying a piece of rubber pressure tubing—Fig. 1 (C)—is placed in the mouth of the tube. The tube is evacuated, and closed by means of a screw clip on the pressure tubing. The end of the latter is then attached to the delivery tube of the cuprammonium storage bottle, and cuprammonium admitted until it is about 4 cms. from the mouth of the tube. The viscometer is then disconnected, and the cotton rapidly agitated in the tube by means of a thin steel rod so as to expel any bubbles of ammonia gas which may have been trapped in the tube. The weight is introduced, the tube completely filled with cuprammonium solution, and closed by means of the specially designed stopper. The tube is then shaken by hand so as to distribute the cotton evenly along the length of the tube. A uniform solution is obtained by rotating the tube end over end at a speed of 1·5 r.p.m. for several hours. During the process of solution care should be taken to exclude light from the tubes.

Measurement of Viscosity

The apparatus used in the actual measurement of viscosity is shown diagrammatically in Fig. 2. A is a galvanised iron tank, containing water, which is maintained at a constant temperature of 25° C. by a small regulating burner B, the supply of gas to this being controlled by the thermoregulator C. Two large burners, DD, connected to an independent gas supply, are used to raise the water to approximately the required temperature at the commencement of the work. One or more bars E are fitted to the tank, and carry a number of spring clips by means of which the tubes F, containing the cuprammonium solutions of cellulose are suspended in the water, until the solutions have attained the temperature of 25° C., at which the actual measurement is made.

During the actual measurement of viscosity, the tube is suspended by means of a clip G, in a cylindrical glass vessel H, through which water is circulated by means of the glass centrifugal pump K, situated in the tank A. The water in the vessel H is changed three times per minute, returning to the tank by the overflow. The clip G can be adjusted in two directions so that the suspended tube is exactly vertical, and also slides vertically along the parallel rods LL.

When the solution in the tube has reached the required temperature, a small volume of the solution is carefully poured out of the tube so that the level is about 2 cms. from the open end. A rubber stopper, bored centrally,

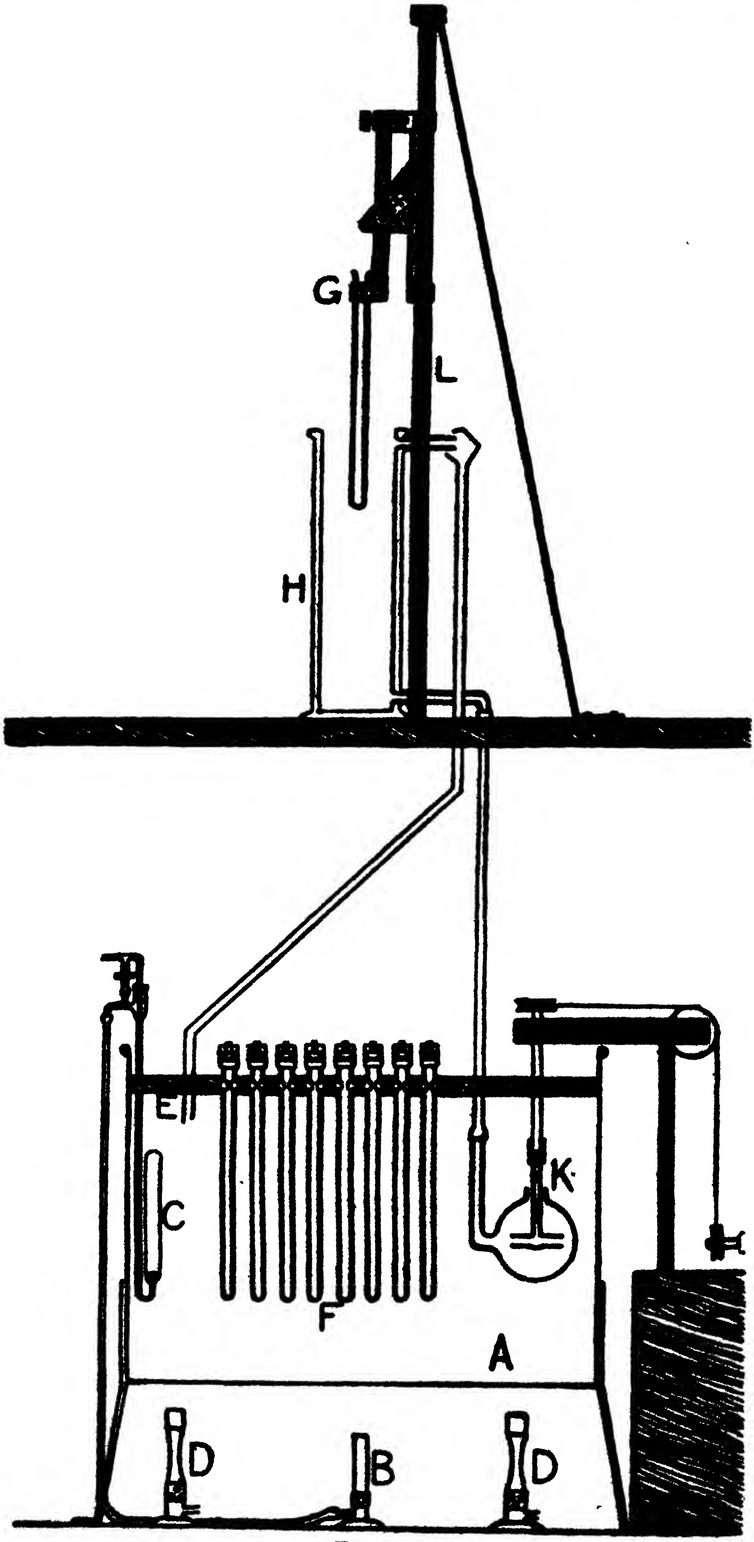

FIG. 2

carrying a short length of glass tubing, is introduced so that the glass tubing dips about 1 cm. below the surface of the solution. A small hole in the wall of the tubing, just below the rubber stopper, allows for equalisation of pressure. The viscosity tube is placed in position in the vessel H. Steel ball bearings ($\frac{1}{32}$ in. diameter) are dropped down the small tube, and the time of fall in seconds between the two etched rings on the viscometer is noted. From the observed times the viscosity of the solution is calculated according to the formula[3]—

$$\eta = \frac{2gr^2(s-\sigma)T}{9l\left(1+2{\cdot}4\frac{r}{R}\right)\left(1+3{\cdot}3\frac{r}{h}\right)} \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

where η = viscosity of cuprammonium solution of cotton.
g = gravitational constant (981).
r = radius of sphere ($\frac{1}{64}$ in. $= {\cdot}0397$ cms.).
s = density of steel sphere (7·81).
σ = density of cuprammonium solution (0·942 for 1% soln.).
(0·952 for 2% soln.).
T = time of fall of sphere.
l = distance between etched rings (15 cms.).
R = internal radius of tube (0·5 cm.).
h = total height of liquid (approx. 26 cms.).

If the time of fall is inconveniently small, a stronger solution (1½% or 2%) should be prepared, and the determination repeated.

Expression of Results

Results are usually expressed in terms of log. viscosity of a 2% solution. This value can be obtained from the observed value for 1% solution by means of the formula[6]—

$$1 + \frac{C}{m} = \frac{B}{\log.\,\eta - \log.\,\eta_1} \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

where C = a constant.
B = a constant = 11.
m = concentration of solution (g. cotton per 100 c.c.).
η = viscosity of cuprammonium solution of cotton.
η_1 = viscosity of cuprammonium solution = 0·0152 poise.

The values of log. viscosity for 2% solutions, corresponding to various times of fall, have been calculated from equations (1) and (2), and the results expressed graphically. (Table I and Fig. 3.)

Table I—Calculated Values of Log. η for 2% Solutions

Strength of Solution used	Time of Fall in Seconds								
	1	2	5	10	20	40	60	80	100
1%	$\bar{1}$·91	0·41	1·03	1·48	1·90	2·31	2·54	2·69	2·82
1·5%	$\bar{1}$·39	$\bar{1}$·77	0·26	0·62	0·98	1·33	1·53	1·66	1·78
2·0%	$\bar{1}$·12	$\bar{1}$·42	$\bar{1}$·82	0·12	0·42	0·72	0·90	1·02	1·12

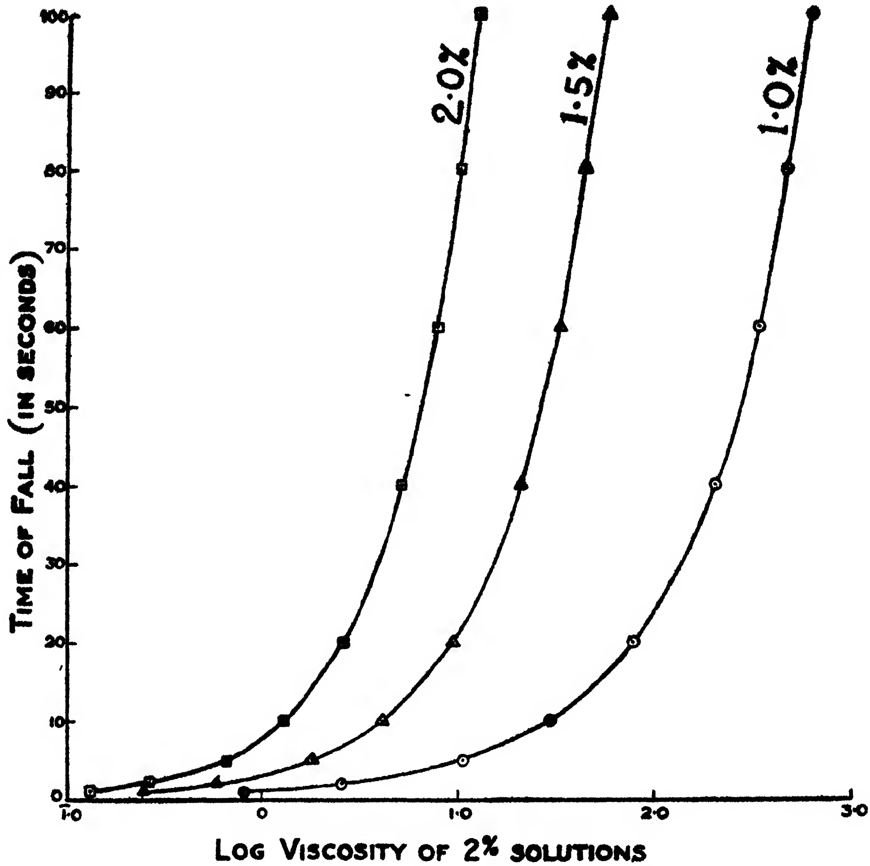

FIG. 3

SUMMARY

Methods previously employed for the determination of the viscosity of solutions of cellulose in cuprammonium are discussed, and an improved method of procedure is proposed.

The authors' thanks are due to Mr. W. H. Butler for assistance in the design and construction of the apparatus, and also to Messrs. Tootal Broadhurst Lee Company Limited, for permission to publish this paper.

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18—A COMPARISON OF SOME METHODS OF TESTING THE BREAKING STRENGTH OF SINGLE COTTON FIBRES

By HARIRAO NAVKAL, M.Sc., and K. R. SEN, M.Sc.
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SUMMARY

The present paper deals with the merits and demerits of three types of instruments, which are used for the determination of the breaking strengths of single cotton fibres, viz. the hydrostatic (O'Neill's), the balance (Barratt's), and the pendulum (Balls' Magazine Hair Tester).

Various results are given for the different instruments. It is shown that the mean obtained by Barratt's is higher than that obtained by the other two, of which O'Neill's gives the higher value. Replacing the water in the latter instrument by calcium chloride so as to regulate the humidity at which fibres are broken, lowers the mean and renders it but little different from that obtained by the Magazine Hair Tester. Results obtained at the Technological Laboratory for 39 cottons tested on both the instruments are given, from which it is deduced that, on the average, the Magazine Tester gives a value which is only 2½% greater than O'Neill's; a part at least of this difference is attributed to the greater speed at which fibres are broken by the Magazine Tester.

The errors of the three instruments are discussed in detail. It is concluded that the value got by the Barratt Tester is much higher than that got by the other two, both of which seem to agree fairly well if a large number of readings are taken and if calcium chloride solution is used instead of water in the O'Neill Tester; the Magazine Tester has the advantage in speed of working and the O'Neill Tester in economy of first cost.

INTRODUCTION

There is no doubt that the strength of a cotton yarn is dependent upon the strengths of its constituent fibres. The investigation of the relationship between the two necessitates the determination of fibre-strength, and this is attended with much difficulty, chiefly because the fibre-strength varies greatly from one fibre to another in any one sample. Some method is therefore needed by which the fibre-strength may be measured both accurately and speedily. The present paper relates to the merits and demerits of three types of instruments used to measure the strength of single fibres. These types of instruments are the hydrostatic, the balance, and the pendulum.

In the different types, one end of the fibre to be tested is fixed to a rigid support, while the other is pulled by a hook attached either to a float, the beam of a balance, or the pendulum.

TYPES OF INSTRUMENT FOR MEASURING FIBRE-STRENGTH

(1) Hydrostatic Type

This was the first to be used for this kind of work, by O'Neill as early as 1863[1]. It consists essentially of a long cylindrical tube containing liquid which is drained off in a measuring cylinder; and a float, which in its simplest form consists of a corked test tube weighted with mercury, and which floats in the liquid. The fibre is stretched between two hooks, one of which is fixed to a framework and the other is attached to the float.

In 1902, Yves Henry modified the O'Neill apparatus by using a graduated float, and reading the difference in level of this float instead of the volume of water. Improvements due to F. Hughes[2] consisted of an easy method of mounting fibres, and an arrangement of a fine-drawn outlet tube so that the water should flow at a fairly constant rate.

The O'Neill apparatus used in the present experiments is shown in Fig. 1. It is a modification due to Mann and Peirce,[3] who introduced a lever arrangement for helping in the adjustment of the fibre in its zero position. HS is the cylinder containing the liquid, F is the float. The lever is a threaded rod, on which is a nut W, which allows of the lever system being readily

balanced about the fulcrum P_1, consisting of two needles resting in a V-groove; a third needle P_2 is attached to the end of the lever, and has a very restricted movement in a vertical plane between two stops. At the beginning of an experiment the nut W is so adjusted that needle P_2 just rests on the lower

O'NEILL'S HAIR TESTER.

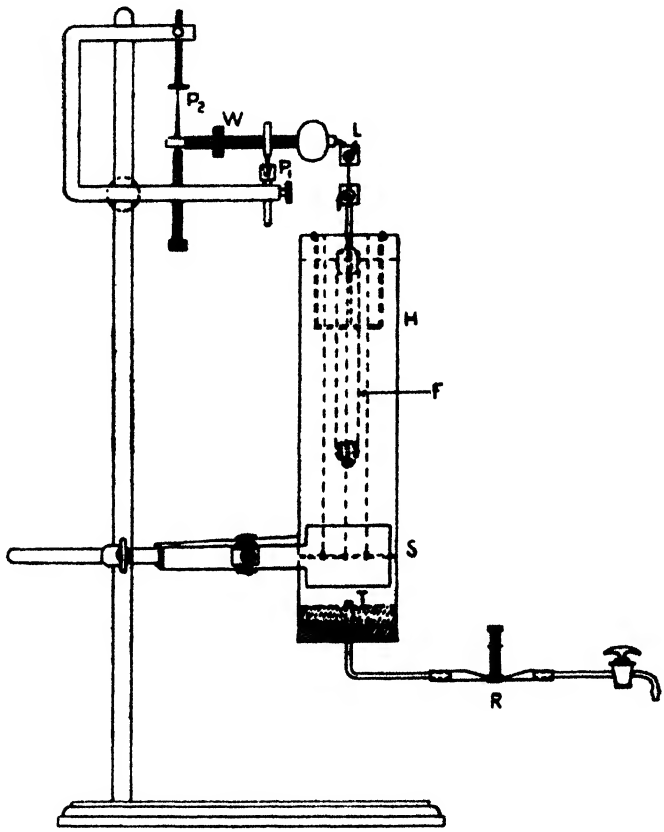

FIG. 1.

L A LEVER ARRANGEMENT TO STRAIGHTEN THE FIBRE WITHOUT APPLYING TENSION
W A SLIDING WEIGHT TO REGULATE THE BALANCE OF THE LEVER.
P_1 & P_2 POINT-AND-LINE ARRANGEMENTS
H AN INVERTED TRIPOD TO KEEP THE FLOAT VERTICAL
S A SUPPORT TO PREVENT THE FLOAT FROM STRIKING THE OUT-LET-TUBE-PROJECTION "T" AFTER THE BREAKING OF A STRONG FIBRE
R PINCH-COCK TO REGULATE THE FLOW.

stop; the liquid is then drained off till P_2 just moves up to the upper stop. Any further draining off of the liquid must produce a tension in the fibre, and from this point onward the liquid, as it is drained off, is collected in a measuring cylinder. The flow of the liquid is stopped when the fibre breaks, and from the volume of the liquid collected in the measuring cylinder it is easy to calculate the breaking strength, either by a formula or by means of a graph obtained from a previous calibration.

(2) Balance Types

Bowman[4] used an instrument of this type but does not describe it in detail, merely stating that he used "a lever machine, with a sliding bar, which was specially constructed for the author."

Matthews[5] used nearly the same arrangement. One end of the fibre was fixed to a rigid support, while the other was clamped between the jaws suspended from one end of the beam of a balance, from which the pans had been removed. A sliding weight was caused to move along the other arm until the fibre broke. The movement of this bar was controlled by a rack and pinion arrangement so that a gradually increasing force could be applied on the fibre.

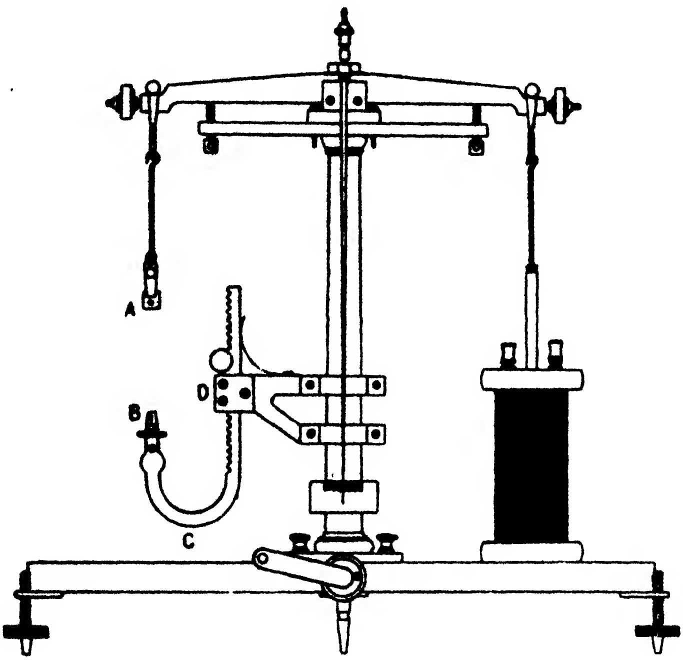

Fig 2

The Bureau of Plant Industry at Washington, U.S.A., has used a similar machine. These two methods are rather difficult to work and the labour involved in their working is also very great. A modified form of this apparatus used by Barratt is a good instrument of this type, and has been used in the present experiments. Fig. 2 is a diagram of this apparatus. From one end of the beam of a balance, from which pans are removed, is suspended a hook A. One end of the fibre is suitably attached to this hook, and the other end to a rigid support C. By moving a screw at D, the distance AB can be varied. From the other end of the balance beam is suspended a steel rod, most of which is inside a solenoid, the current through which is varied by means of an adjustable resistance in the electrical circuit. At the beginning, there is no current in the solenoid. The screw at D is so regulated that the fibre is straightened without having any extra tension applied to it. A small current is allowed to flow in the circuit and is gradually increased till the fibre breaks. The reading of a milliammeter in the circuit is then taken, and this, from a previous calibration, indicates the breaking strength of the fibre.

Another important instrument of this type has been invented by P. Krais[8] and is called "Deforden" by the manufacturers. The pans of a balance are removed and from one end of the beam is suspended a hook attached to the fibre to be tested. Except for minor differences, the arrangement here is similar to that of Barratt's. From the other end of the beam is suspended a vessel into which water flows from a graduated burette until the fibre breaks. This instrument has been extensively used in finding the resistance of silk and wool fibres.

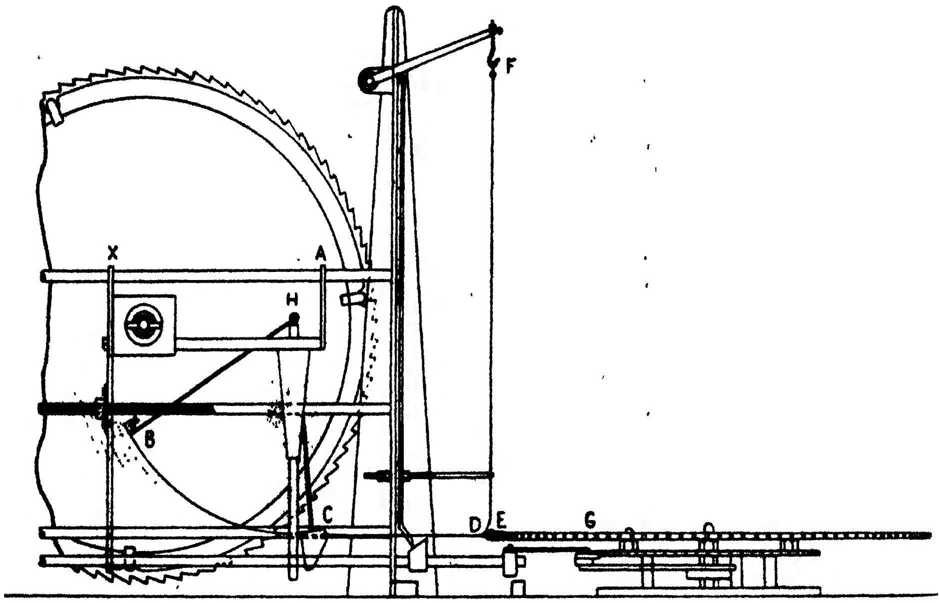

Fig 3

The Heim Richard microdynamometer[9] is a different form of the balance type for measuring the breaking strength and extension of wool. In this case the load is applied by lowering a vessel containing mercury, thereby withdrawing support from a float attached to one end of the beam of the balance, and so producing a tension in the fibre attached to the other end of the beam.

All these instruments, except Bowman's, have various arrangements to measure the elongation of fibres.

(3) Pendulum Types

The Schopper machine is based on the pendulum principle. The tension on the fibre is made to lift a pendulum and can be measured by means of the angle through which the pendulum has been rotated.

Balls[7] gives a method by which a bunch of fibres is broken by a swinging pendulum. If a pendulum, working in frictionless bearings, falls from a certain height, it rises to the same height on the other side. "At the lowest point of the swing, the apex of the pendulum meets the end of a slot in a piece of tough paper and carries it along with it." During this process, a bunch of fibres is broken and as the pendulum expends some energy, it rises to a lesser height on the other side. On a smoked plate a delicate bristle stylus attached to the pendulum registers the regular displacement. From this record the energy expended in breaking the fibres can be calculated.

Balls[8] subsequently developed his Magazine Hair Tester, which is an automatic instrument for measuring the strength of single fibres. Fig. 3 is a diagram of part of the apparatus, and Fig. 4 a photograph of the complete instrument. It consists essentially of a compound pendulum HBC which is attached to a suspended hook FD by means of a silk thread. This hook drops into an eyelet E, to which one end of the fibre is attached, while the other end is attached to a magazine disc G; this magazine has spaces for mounting 50 fibres in this way. The pendulum swings in frictionless cup-and-vee bearings on steel points; its angular displacement is recorded by means of an electric spark between an attached needle B and a plate opposite to it. The plate is covered with a thin paper on which the electric spark burns a line whose length depends on the strength of the fibre. The motion of the pendulum is caused by its being mounted on a carriage, which moves along an endless screw in either of the directions AX or XA; as long as the fibre does not break, if the carriage moves along the direction AX, the line HC is inclined more and more to the vertical and the force that is required to hold it away from the position of equilibrium becomes greater and greater. This goes on till the fibre breaks. After a time, the motion of the carriage is reversed, the magazine disc G moves round one space, the hook FD is raised, and when the pendulum reaches its original position, the hook lowers itself into the eyelet of the next space. Once more the forward motion begins and the next fibre is broken, and so on. The record consists of a series of charred lines on the piece of paper; by the use of a calibrated scale, the breaking strength of all the fibres is determined.

COMPARISON OF VALUES OBTAINED FOR THE SAME COTTON BY THE THREE HAIR TESTERS

The three instruments, viz. O'Neill Tester, Barratt's Fibre Balance, and Balls' Magazine Hair Tester may be regarded as representative of the three different types; two cottons have been tested by the authors on all the three instruments, and a third cotton was tested on the last two instruments only.

From these results it appears that the mean obtained by the Barratt is decidedly higher than those got by the other two instruments, of which the O'Neill gives a higher value than the Balls. These differences cannot be attributed to any personal equations, or a fluctuation of humidity, or an insufficiency in the number of fibres tested, for the table shows that both the authors have got practically the same value as long as the instrument is the same. The humidity of the laboratory also was the same throughout, and the number of tests was large. It may also be mentioned that the variation in strength for the first cotton is much smaller than for many other Indian cottons.

Dharwar No. 1

Observer	Instrument	Breaking Strength (g.)	No. of Tests
Harirao Navkal	Balls	4·66	1,000
K. R. Sen	Balls	4·62	400
Harirao Navkal	Barratt	5·12	1,000
K. R. Sen	Barratt	5·10	400
K. R. Sen	O'Neill	4·89	250

Probable error of a single observation = 32% of the mean.

Aligarh A19

Observer	Instrument	Breaking Strength (g.)	No. of Tests	R.H. (%)
Harirao Navkal	Barratt ...	7·22	360	78
Harirao Navkal	Balls ...	6·13	360	79
K. R. Sen	O'Neill ...	6·67	250	–

Probable error of a single observation = 33% of the mean.

Punjab-American 4F

Observer	Instrument	Breaking Strength (g.)	No. of Tests	R.H. (%)
Harirao Navkal	Balls ...	3·89	300	60
Harirao Navkal	Barratt ...	4·39	300	61

Probable error of a single observation = 38% of the mean.

COMPARISON OF VALUES OBTAINED BY THE BALLS TESTER AND THE O'NEILL TESTER

Whereas we could be certain of the humidity at which the fibres were tested on the Balls and the Barratt instruments, we could not be very sure of it when the O'Neill was used, as long as water was used as the liquid in the tube HS, for as pointed out by Mann and Peirce, the space just above the water is saturated, so that the relative humidity of the air near the fibre may have any value between 100% and the prevailing atmospheric humidity. To avoid this uncertainty, the method of Mann and Peirce has been followed of using calcium chloride solution instead of water; the strength of this solution is regulated so that its vapour pressure practically corresponds to the prevailing relative humidity of the atmosphere. This is now the standard practice in the routine testing of cottons for fibre-strength at the Technological Laboratory. The values obtained by the Balls and O'Neill methods for the standard Indian cottons of 1926–27 and 1927–28 have been given in "Technological Reports on Standard Indian Cottons, 1928"[10]; each value

is the mean of 300 tests. These results are reproduced in the following table—

Season	Cotton	Strength (g.) Balls (*a*)	Strength (g.) O'Neill (*b*)	$\frac{100(a-b)}{b}$	Relative Humidity (Balls) (%)	Relative Humidity (O'Neill) (%)
1926–27	Dharwar 1	5·18	4·60	13	80	77
1927–28	,, ...	4·20	4·10	2	62	65
1926–27	Gadag 1	4·07	3·97	3	68	78
1927–28	,, ...	4·06	4·30	−6	72	66
1926–27	Surat 1027	4·77	4·80	−1	67	67
1927–28	,, ...	4·32	4·72	−8	62	60
1926–27	Wagad 4	5·35	5·08	5	75	74
1927–28	,, ...	3·12	2·80	11	57	66
1926–27	Wagad 8	5·27	5·09	4	77	75
1927–28	,, ...	3·83	3·01	27	64	64
1926–27	P.A. 4F	3·89	3·72	5	75	72
1927–28	,, ...	3·91	4·30	−9	56	54
1926–27	P.A. 285F	2·93	3·70	−21	72	74
1927–28	,, ...	3·78	3·58	6	67	67
1926–27	P.A. 289F	3·43	2·85	20	71	75
1927–28	,, ...	3·14	3·88	−19	49	56
1926–27	Mollisoni	4·86	4·70	3	79	76
1927–28	,, ...	5·26	4·80	10	51	52
1926–27	Aligarh A19... ...	5·44	5·48	−1	80	77
1927–28	,, ...	5·25	5·55	−5	68	56
1926–27	Cawnpore K22 ..	5·26	5·10	3	76	78
1927–28	,, ...	4·50	4·68	−4	53	58
1926–27	J.N. 1	5·29	5·28	0	77	78
1927–28	,, ...	5·06	5·38	−6	50	59
1926–27	C.A. 9	4·84	4·46	9	77	77
1927–28	,, ...	3·77	4·21	−10	54	57
1926–27	Cambodia Co 1 ...	3·97	3·41	16	75	80
1927–28	,, ...	3·87	3·96	−2	72	69
1926–27	Nandyal 14	7·30	5·67	29	76	78
1927–28	,, ...	6·38	6·56	−3	69	69
1926–27	Hagari 25	3·23	3·15	3	76	73
1927–28	,, ...	4·26	3·46	23	72	70
1926–27	Karunganni C7 ...	5·55	5·51	9	76	78
1927–28	,, ...	4·96	4·45	11	56	57
1926–27	Umri Bani	5·40	5·22	3	67	77
1927–28	,, ...	4·26	4·98	−14	48	54
1927–28	Cambodia 440 ...	3·56	3·32	7	66	69
1925–26	Memphis	4·35	4·52	−4	72	72
1925–26	Texas	4·94	4·48	10	72	72
	Grand Mean ...	4·53	4·42	−2·5	67·6	68·6

Thus, in the foregoing table, we have 39 cottons, tested for strength on both the instruments. Except in six cases, there is no great difference between the last two columns, i.e. in most cases the humidity has been nearly the same. On the average the Magazine Hair Tester gives a value which is only 2·5% greater than the O'Neill, though in eleven cases the difference between the two values is more than 10 per cent. Part of the difference is due to the idiosyncrasies of the instruments, but a part of it also is due to the fact that fibres are broken at a much higher speed in the Balls than in the O'Neill. The rate of loading for the Balls Tester is about 0·4 g. to 0·5 g. per second, while it is 0·03 g. per second in the case of O'Neill. Reference to this will be made later.

DISCUSSION OF ERRORS

We may now discuss the errors that are peculiar to each of the three instruments.

(1) O'Neill Tester

This is the simplest instrument as it does not depend on any mechanical adjustment.

We have to take care to see that the zero is adjusted accurately, and the float so made that it stands vertically, without touching the sides of the reservoir. As already explained, a proper choice of tubes must be made to lessen the errors due to the extension of the fibre. The desirability of using a solution of calcium chloride in this apparatus has already been referred to (page T272); in practice, where the atmospheric humidity changes rapidly, this changing of solutions is bound to be tedious and a certain amount of approximation has always to be made.

After all these precautions have been taken, the instrument has the following defects—

(1) It is impossible to stop the flow of liquid at the exact moment when the fibre breaks, for a few extra drops always flow out. If the rate of flow is small, the error due to this is not very great.

(2) The liquid does not flow out at a uniform rate, as the "head" gradually decreases. Hence there is a fall in the rate of loading. This fault is also found in the Barratt instrument.

(3) Mann and Peirce[3] have shown that the rate of loading has a considerable effect on the breaking strength till the rate is fairly high. Beyond this limit the strength is independent of the rate of loading. But to work at this limit results in an increase in the error due to (1).

(2) Barratt Tester

(1) We can never stop increasing the pull (i.e. decreasing the electrical resistance) exactly at the right moment, and there is always a chance of overstepping the limit. The error due to this is considerable when a fibre is very strong, because when the variable resistance in the circuit is very small, a slight change made in it makes a very great change in the pull. This error is lessened by reading the milliammeter just before and after the fibre breaks, the mean of the two values gives a more accurate representation of the strength.*

(2) The fibre, during the process of mounting, undergoes a greater strain in this instrument than in any of the others, and weak fibres are liable to be broken during the preliminary adjustment. This has a marked effect on increasing the mean when a cotton containing very weak fibres is tested.

(3) The rate of loading is also low, but not so low as in the O'Neill Tester.

The first two defects tend to increase the mean, the third to decrease it.

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* At a later date—subsequent to the experiments referred to above—this defect has been remedied to a considerable extent by using a thin constantan wire along with a rheostat in the electrical circuit. The length of this wire can be very accurately regulated or varied without disturbing any other part of the circuit. In the beginning the rheostat is adjusted to 300 ohms and then is gradually reduced to zero. At this stage, the only variable resistance in the circuit is this wire and as its length is gradually diminished, the current can be increased—slowly, steadily, and at any rate that is desired.

(3) Balls Magazine Hair Tester

This instrument may have the following defects—

(1) Uncertainty in the calibration of the scale which is supplied with the instrument; this difficulty is avoided by re-calibration.

(2) The spark is not always normal to the plate, hence the line that is burnt is sometimes shorter or longer than it should be. It has been noticed that the spark "lags" in the great majority of cases and hence makes the mean lower.

(3) The line described by the electric spark on the recording paper is discontinuous, being made of a series of dots. The fibre may have been broken at any time after the last dot was made and before the next one was about to be made; in fact it rarely happens that a fibre breaks just when the last dot is made. Hence this error also makes the mean lower.

(4) The friction between the magazine and the eyelets varies, and cannot be estimated.

RATE OF LOADING

We may note that the fibres are broken at the maximum speed in the Balls' instrument, in which the weight is applied at the rate of 0·4 to 0·5 g. per second, whereas it is about 0·13 g. per second in the case of the Barratt instrument. However, the speed can only be very approximately determined, as it varies considerably even for the same person at different times; moreover, it is higher for the stronger fibres. For the O'Neill Tester it has been observed that the best rate of flow causes the load on the fibre to increase at a rate somewhere between 0·023 and 0·037 g. per second. It is true that we could increase the rate of loading in both these instruments and we can even make them approach 0·4 g. per second, but when this is attempted, the stopping of the increase of current or the flow of liquid at the right time becomes well-nigh impossible, and the values suffer considerably due to this error. Mann and Peirce[3] have given a formula to find the difference in the mean strength value, when the speed is different. We have thought that its application to the Indian cottons is not justified because if the formula were applied, the mean obtained by the Balls Tester should be greater by about 5·5% than that got by Barratt's, and the mean got by O'Neill's should be about 12% less than that got by the Balls. We have already seen that such large differences are not observed. It is, however, true that a greater speed is always associated with greater strength, and hence the value got by the Balls Tester is rather greater than that by O'Neill's. If it were only a question of speed, the value got by the Barratt Tester should have been lower than that got by the Balls, but the other defects of that instrument counteract this and actually we get higher values with the Barratt.

CONCLUSION

From what has been said, it is clear that for various reasons the value got by the Barratt Tester is much higher than that got by the Balls and the O'Neill testers, both of which seem to agree fairly well, if large numbers of readings are taken. It may be mentioned, however, that any of these three instruments could be used when comparative values only are required.

More fibres could be broken in an hour by the Balls Tester than by the other two, while work on O'Neill's could be carried on only at a slow rate. From the point of view of first cost, O'Neill's has the advantage because of its simplicity of construction; it has no mechanical error, and, therefore, the values that are got from it are reliable.

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[10] Turner, A. James, "Technological Reports on Standard Indian Cottons, 1928," p. 117.

Further results are now available in "Technological Reports on Standard Indian Cottons, 1929," pp. 121–2.

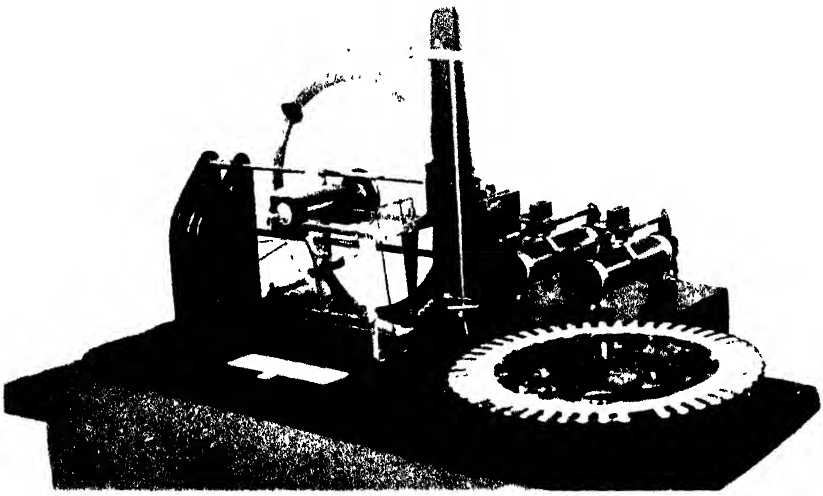

FIG. 4

FIG. 1

Colonies of mildew fungi and bacteria developing on sterilised wort agar. Each glass dish was inoculated with 4 sq. cm. of a clean grey cloth.

The small white spots towards the top-right are colonies of bacteria. The black spot at the extreme right is a growth of *Cladosporium*

The large white mass is a colony of *Fusarium*

The powdery black mass is a colony of *Aspergillus niger*.

19—THE FUNGI CAUSING MILDEW IN COTTON GOODS

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I—SUMMARY

In connection with the routine examination of mildew cases, and with the testing of antiseptics suitable for use in sizing, it has been necessary to isolate a considerable number of mildew fungi in pure culture. This paper gives a brief summary of the occurrence and characteristics of the types thus isolated, and of the difficulties encountered in a preliminary classification.

The majority of species belong to the two genera *Aspergillus* and *Penicillium*, but *Fusarium* and other *Fungi Imperfecti* are of common occurrence. It is shown that the raw cotton itself is the principal source of infection. Only a proportion of the fungi are capable of producing stains on cloth, and a still smaller proportion capable of causing tendering under ordinary conditions of exposure.

II—OCCURRENCE OF MILDEW FUNGI

The term mildew as understood in the cotton industry applies to any fungal growth producing an undesirable effect—usually a discoloration—on cloth or yarn. Mildew may occur at all stages of manufacture; in raw cotton, in yarn, in unbleached cloth, and in dyed or printed goods. It causes most loss, however, in grey (unbleached) cloth, and claims for mildew in goods of this class shipped to Eastern markets are of regular occurrence. This is said to be especially so in times of trade depression, when goods are liable to be kept longer in storage.

A more complete general statement of the mildew problem has been given by Bright, Morris, and Summers.[6] The mildew collection described in the present paper consists in part of cultures isolated by these workers.

III—SOURCE AND EXTENT OF INFECTION

All cotton goods are infected with mildew organisms, since spores are continually being deposited from the air. Cloth and yarn in the grey state have in addition the heavy infection present in the raw cotton. Some species of mildew (e.g. *Aspergillus niger*[12a]) are traceable right back to the cotton field, where they cause diseases of the boll.

The heavy infection of an odourless and apparently clean grey cloth is illustrated in Fig. 1, where "colonies" of moulds and bacteria growing on the medium in each circular dish have developed, after several days, from 4 sq. cm. of the fabric teased out into warp and weft and scattered over the medium. A somewhat similar experiment is recorded by Osborn[12].

The extent of infection cannot easily be expressed by a numerical value, since the fungi are present not only as spores but also as mycelium (the thread-like stage of the fungus) in and among the cotton hairs, and either form is capable of giving rise to a fungus colony. The same difficulty is encountered by workers on soil microbiology (Waksman[18]).

Mildew spores and mycelium readily stain with the dyestuff Cotton Blue, whilst cotton hairs do not. A technique based on this[4] greatly simplifies the microscopic examination of a fabric suspected of mildew.* A more rapid

*Warm the specimen in lactophenol (lactic acid 1, phenol 1, glycerin 2, distilled water 1) on a glass slide for 1 minute. Transfer to cotton blue (1% aqueous solution) and warm several minutes. Wash in water, then warm with lactophenol until as much as possible of the colour is removed. Mount in lactophenol.

but somewhat less satisfactory preparation may be made by staining with warm picro-aniline blue and washing with water.

IV—METHODS OF CONTROL

Since infection cannot be avoided, methods of control of mildew are based on the prevention of further growth, and it cannot too often be emphasised that the principal factor is the amount of moisture present. The available evidence in the literature indicates that in cloth with 8% moisture regain or less, no further development of mildew will occur.[1] Samples of three different grey cloths kept in the laboratory with moisture regains of 8 to 10% confirm this; after three months' incubation at 25° C., cloths with 8·5, 8·9, and 9·0% regain showed no mildew, whilst cloths with 9·5 and 10·0% showed very slight growth.

In practice, however, it is not always possible to ensure this low moisture regain, and the use of an antiseptic becomes necessary. Mildew organisms show very large specific differences in their behaviour towards antiseptics,[11] and it is largely because of this wide variation that it has been considered worth while to classify the organisms that are most frequently encountered. The most resistant of the species commonly occurring have been chosen for exhaustive antiseptic tests, the results of which are recorded in the following memoir.

A third possible method of suppressing mildew growth is to maintain a high concentration of carbon dioxide in the storage atmosphere, though this is not practicable for cotton goods, except perhaps in special instances. Preliminary experiments have shown that in an equal mixture of air and carbon dioxide the growth of certain cotton mildews is very considerably suppressed, whilst air containing even 25% carbon dioxide exerts an appreciable effect. These figures may be compared with the results of Bavendamm[2] who found that with 32 species of wood-destroying fungi, 19% excess carbon dioxide checked growth, and 80% completely inhibited growth; or with those of Brown,[7] whose test fungi were appreciably affected by 20% carbon dioxide and almost all suppressed by 60 per cent.

V—DISTRIBUTION OF VARIOUS TYPES OF MILDEW FUNGI

The list given in Table I shows the source of a number of fungi that have been isolated. The classification is by no means complete, and represents a preliminary attempt to sort the collection into groups of closely related types, rather than to attain an exact identification (not always possible) of species. The principles on which the classification is based are discussed in greater detail in Section VII. All the laboratory record numbers are given, and pure cultures are being maintained at the Shirley Institute.

It will be seen that there is little correlation between source and species. *Aspergillus niger*, for example, occurs in raw cotton, as an infection of the air of the mill, and in cloth mildewed at home and abroad. It has frequently been observed both in grey cloth and as a frequent cause of spotting in alizarine prints. This indicates the impossibility of using the identification of the causal organism as a means of tracing the stage at which mildew occurred.

There are, however, a few general remarks that can be made with respect to distribution. The two genera, *Aspergillus* and *Penicillium*, are the most abundant. *Penicillium* species tend to grow at lower temperatures than *Aspergillus* species, and hence are more frequent in mildew developing in

this country, whereas *Aspergillus* species are more common in mildew developed in hot climates. In this connection it is interesting to notice that Waksman[17] in a study of the fungal flora of American soils, found that in the warmer south *Aspergillus* was the predominant genus, whilst *Penicillium* and *Mucorales* were found more extensively in northern states.

The degree of humidity also determines to some extent the types that predominate. The series of fungi forming the *Aspergillus glaucus* group is of common occurrence in cloth of moisture content near the limit of growth. This agrees with an observation of Thom and Le Fevre[16] that in corn meal this group is the first to develop as the moisture content rises above 12·5–13·0 per cent. Fortunately, the *Aspergillus glaucus* group is very susceptible to most antiseptics.

VI—THE EFFECTS OF MILDEW

The effects may be summarised briefly as (1) musty smell, (2) coloured stains, (3) production of acid (or alkali), and (4) tendering.

(1) *Smell*—A musty odour usually accompanies the development of mildew in a confined space, and often precedes any visible effect on the cloth. The smell soon disappears if the cloth is freely exposed to air, and it is a common practice to open up and replait cloth that has developed a musty smell during storage.

(2) *Stains*—This is by far the most important effect, and is the cause of the majority of mildew claims. Two sorts of staining may be noted. In the first, the discoloration is due to the formation of masses of coloured spores; this type usually occurs under moist conditions, and such stains can sometimes be removed by brushing. In the second type of stain, the colour is due to pigment formation by the fungal hyphæ or the perithecia of certain mildews, or to coloured products formed by the action of the mildew on starch and other food substances present.

In dyed goods the dye may be changed in colour by acids or other substances produced by the mildew fungus—see (3).

Table I indicates those species in culture that produced definite stains when inoculated on strips of sterile grey cloth. The strips of cloth were placed in test tubes, the lower end of the cloth dipping in water; the tubes were then plugged with cotton wool, sterilised, and then inoculated and incubated at 25° C. in the usual manner.

It should be noted that the colour of the stain may be affected by various factors, such as the reaction of the cloth, the presence of other organisms, and certain chemical substances. The brown stain produced by *Aspergillus terreus* 48, for example, is greatly intensified in the presence of traces of zinc chloride.

Where "nil" appears in Table I in the column headed "Cloth Stains" the species failed to give stains under the conditions of test; it by no means follows that none would cause stains under the varying conditions met with in actual practice. Some in fact, are known to do so, e.g. certain *Aspergillus glaucus* spp. sometimes produce orange or yellow stains due to coloured perithecia.

(3) *Production of Acid from Starch*—This is closely connected in its commercial aspects with (2) since its principal importance lies in its connection with the spotting of coloured fabrics, such spotting being usually traceable to acid produced by mildew. Witz[20] observed in 1876 that the spots had an acid reaction, but considered that the acidity was "probably due to the

formation of lactic and butyric acids in fermentation" by bacteria present. Since that time much work has been published on the production of gluconic, oxalic, and citric acids by *Aspergillus niger* and other fungi.

The great variation in acid production by different species is shown in Table I. This gives the results obtained by growing a number of pure cultures (at 25° C. for one week) on a 3% maize starch paste coloured by litmus. Some species, such as *Cladosporium* 15, and *Aspergillus versicolor* 45, produce no appreciable acid. *Aspergillus niger* (e.g. sp. 169) on the other hand, is one of the most vigorous acid producers and it is not surprising that spotted prints have usually yielded this type as the predominant infection.

Similar spotting may be produced by a nutrient sugar solution on which *Aspergillus niger* has been growing for some days, or by 0·2% oxalic acid or by 0·3% citric acid.

(3a) *Production of Alkali*—Many fungi when grown on a nitrogenous substratum are capable of ammonia production. It is, therefore, not surprising to find that a number of mildew fungi when grown on unbleached cotton produce an appreciable alkalinity.

In unbleached cotton goods containing starch, however, alkalinity due to fungi is more rare, either because the protein is not attacked when there is an abundant supply of starch, or because alkali production is masked by acid production.

Only a few of the fungi examined [*Cladosporium*, *A. versicolor*, *Penicillium* series (a)] actually cause alkalinity on sized cloth and such species naturally do not include those that form considerable acid from starch. On raw yarn both *Cladosporium* 15 and *Aspergillus flavus* 35 produce alkali; on grey cloth only the former does so.

It should be noted that in practice grey cloth exposed to high humidities rapidly becomes alkaline. Such alkalinity, however, is principally due to the bacteria that commonly accompany mildew and not to mildew fungi themselves.

Table I

Mould Fungi isolated from Cotton Goods.

The reference numbers are those assigned to the cultures maintained at the Shirley Institute. The division of related species into sub-groups is indicated by separate headings.

Species		Source	Cloth Stain under Culture Conditions	Acidity from Starch	Cellulose Decom-position
		ASPERGILLUS			
A. niger group—					
	8	Yarn		Strong	Moderate
	133B	Cloth mildewed abroad		Slight	
	133C	,, ,, in England	Brown	Slight	
	133D	Raw cotton (Queensland)			
	160E	,, ,, (Sakel)			
	169	Cloth mildewed in England	Nil	Strong	
A. glaucus group—					
A. repens	1	Yarn		Nil	Nil
	26	,,			
	56	Cloth mildewed abroad			
	120	Yarn (Egyptian)	Nil		
	129	,, ,,			
A. ruber	23	,,			Nil
	55	Cloth mildewed abroad		Nil	
	115	,, ,, ,,	Nil	Nil	
Allied to *A. chevalieri*	70	,, ,, ,,	Nil		
	80	,, ,, ,,	Nil		

Table I—Mould Fungi isolated from Cotton Goods—*cont.*

Species		Source	Cloth Stain under Culture Conditions	Acidity from Starch	Cellulose Decomposition
		ASPERGILLUS—*cont.*			
A. glaucus group (*cont.*)—					
Allied to *A. chevalieri*	77	Cloth mildewed abroad	Nil		
	89	,, ,, ,,	Nil		
	90	,, ,, ,,			
	106	,, ,, ,,	Nil		
	102	,, ,, in England	Nil	Nil	
	103	,, ,, ,,	Nil		
	157D	,, ,, abroad			
Unidentified	25	Yarn	Nil		Nil
	78	,,			
A. glaucus/fumigatus types	110	Cloth mildewed abroad	Nil	Nil	
	171	,, ,, in England	Nil	Nil	
	179	,, ,, abroad	Nil		
A. fumigatus	74	,, ,, ,,		Strong	Strong
A. fumigatus/nidulans types	71	,, ,, ,,	Nil		
	91	,, ,, ,,	Nil		
	92	,, ,, ,,			
A. nidulans	31	Raw cotton (Zaria)	Yellow/brown	Nil	Strong
A. versicolor group—					
A. versicolor	24	Yarn			
	45	Cloth mildewed abroad	Nil	Slight	Moderate
	46				
	60	Cloth mildewed abroad	Reddish/brown (faint)		
	76	,, ,, ,,	Reddish/brown (faint)	Slight	
	95	Yarn			
	172	Raw cotton	Nil	Nil	
A. Sydowi	173	Flour	Reddish/brown (faint)	Nil	
	44	Cloth mildewed abroad	Reddish/brown (faint)		Moderate
	61	,, ,, ,,	Reddish/brown (faint)	Slight	
	88	,, ,, ,,	Nil	Slight	
	105	,, ,, ,,	Brown		
	131	,, ,, in England	Brown		
	135	,, ,, ,,	Nil		
	167	Yarn		Nil	
A. flavus	35A	Raw cotton (Queensland)		Slight	Moderate
	35B	Yarn (Texas)			
	132	Raw cotton (Durango)		Slight	
	157C	Cloth mildewed abroad			
	157F	,, ,, ,,			
A. effusus	21	,, ,, ,,			
A. terreus	48	,, ,, ,,	Brown	Strong	Strong
A. Wentii	75	,, ,, in England	Yellow/brown	Slight	Moderate
	160A	Raw cotton (Sakel)			
A. ochraceus	73	,, ,, mildewed in England	Brown (faint)	Slight	Moderate
	73A	Cloth mildewed in England			
	162	,, ,, abroad	Red	Slight	
A. tamarii	28A	,, ,, ,,	Brown		Moderate
	28B	Raw cotton			
A. candidus Spp.	11	Yarn		Nil	Nil
	18	Dust		Nil	
	49	,,	Nil		
	52	,,			
	158	Yarn	Nil	Nil	
A. flavipes	175A	,, (Abassi)		Slight	
	175B	,, (American)		Slight	Strong
Unidentified	166	Cloth mildewed in England	Yellow/brown	Nil	
		PENICILLIUM			
Series (*a*)— (?) Related to *P. candidofulvum*, Biourge	85	Air	Green (faint)	Nil	Nil
	87	Yarn (Egyptian)	Green/brown (faint)		
	72	Cloth mildewed abroad			
	116	,, ,, in England		Nil	
	117	,, ,, ,,			
	130	Yarn (Egyptian)	Nil	Nil	Nil

Table I—Mould Fungi isolated from Cotton Goods—*cont.*

Species		Source	Cloth Stain under Culture Conditions	Acidity from Starch	Cellulose Decomposition
		PENICILLIUM—*cont.*			
Series (*b*)— (?) Related to *P. chrysogenum* Thom.	4	Cloth mildewed abroad	Green/yellow	Strong	Moderate
	17	Dust	Green/brown (faint)		Moderate
	42	Cloth mildewed in England	Yellow/brown	Strong	
	50	Yarn		Strong	
	69	Cloth mildewed abroad	Green (faint)		
	79	Yarn			
	101	Cloth mildewed in England	Nil		
	136	,, ,, abroad		Strong	
	176	Yarn		Slight	
	177	Cloth mildewed in England		Slight	
Series (*c*)— (?) Related to *P. citrinum* Thom.	68	,, ,, ,,	Green (faint)		
	94	,, ,, ,,	Green (faint)		Moderate
	97	,, ,, ,,			
	127	Yarn (Egyptian)	Green/yellow (faint)	Strong	
	144	Cloth mildewed abroad	Brown/yellow (faint)	Nil	
	148	Air		Slight	
	156	Cloth mildewed in England			
	157E	,, ,, abroad			
Series (*d*)	2	Yarn	Green/yellow	Slight	Moderate
	98	,,			
	86	Air		Nil	
	119	Yarn	Yellow (faint)	Strong	
Series (*e*)	51	Cloth mildewed abroad	Nil		
	93	,, ,, in England	Nil		Nil
	96	,, ,, abroad	Green/black (faint)		
	107	,, ,, ,,	Nil		Strong
Series (*f*) (?) *P. Roqueforti.*	82	,, ,, in England	Green (faint)		Moderate
Series (*g*)	109	,, ,, abroad	Nil	Nil	Moderate
Series (*h*)	112	,, ,, ,,	Nil	Nil	
	122	Yarn	Black (faint)	Nil	Strong
	123	Cloth mildewed in England		Nil	
Series (*j*) (?) *P. chloro-leucon*, Biourge	114	Raw cotton	Green/black (faint)		Nil
Series (*k*)	137	Cloth mildewed abroad	Green/yellow	Nil	Nil
Series (*l*)	140	,, ,, in England		Nil	Strong
Series (*m*)	154	Dust		Slight	Strong
Series (*o*)	168	Cloth mildewed in England	Nil	Strong	
Series (*p*)	157N	,, ,, abroad			
		OTHER GENERA, INCLUDING FUNGI IMPERFECTI			
Mucor spp.—					
Rhizopus arrhizus	6	Yarn			
	34	Raw cotton (Queensland)		Strong	
	84	,, ,,		Nil	Nil
(?) *M. racemosus*	7	Size		Slight	
Not identified	19	Cloth mildewed abroad			
	29	,, ,, ,,			
	160D	Raw cotton (Sakel)			
Fusarium spp.	32	,, ,, (Zaria)	Nil		
	36	,, ,, (Queensland)		Strong	Nil
	38	,, ,, (Durango)	Nil	Strong	
	67	Yarn			
	146	Starch paste	Mauve	Slight	
	151	Raw cotton	Mauve	Strong	
	160B	,, ,, (Sakel)			
Probably *Fusarium* spp.	83	Cloth mildewed in England	Yellow/black		Moderate
	108	,, ,, abroad			
	139	,, ,, in England	Mauve	Slight	
	152	Air	Yellow	Slight	
	153	,,		Nil	
Cladosporium herbarum	15	Raw cotton (Zaria)	Black	Nil	Strong
	149	Yarn		Nil	
	161D	Cloth mildewed in England			
Alternaria spp.	30	,, ,, abroad			
	37	Raw cotton (Durango)	Purple/black	Nil	Nil
Stemphylium spp.	5	Cloth mildewed in England	Green/black	Nil	Moderate
	124	(?)	Green/black	Nil	Strong

Table I—Mould Fungi isolated from Cotton Goods—*cont.*

Species		Source	Cloth Stain under Culture Conditions	Acidity from Starch	Cellulose Decomposition
OTHER GENERA, INCLUDING FUNGI IMPERFECTI—*cont.*					
Macrosporium sp.	65	Yarn	Green/black	Nil	Moderate
Botrytis cinerea	10	,,			Moderate
Chætomium sp.	170	Raw cotton	Pink (faint)	Nil	Strong
Helminthosporium	141	Yarn	Pink/black	Slight	Strong
Dematium pullulans	66A	,,			Nil
	66D	Size			
Trichoderma sp.	33	Raw cotton		Nil	Moderate
	150	Yarn			Moderate
Monilia spp.	20	Cloth mildewed abroad	Green/black (faint)		Nil
	142	Yarn	Nil	Nil	Moderate
	157B	Cloth mildewed abroad	Green/brown (faint)		Nil
	160C	Raw cotton (Sakel)			
	163	Sago	Black/brown	Nil	
Actinomyces sp.	165	Cloth mildewed in England	Nil	Nil	
Unidentified	3	,, ,, ,,	Green/black	Nil	Strong
	9	Yarn			
	43	Cloth mildewed in England			Moderate
	53	Raw cotton	Black	Nil	
	58	Yarn	Nil		
	113	Cloth mildewed abroad			Nil
	126	Yarn	Nil	Nil	Nil
	128	,, (American)	Green/black	Nil	Strong
	149	,,	Green/black		
	155	Raw cotton	Black	Slight	Moderate
	174	Yarn			

(4) *Tendering*—Tendering or loss of strength is the result of cellulose being attacked by enzymes produced by the mildew fungi or by bacteria. Prolonged attack by certain species of mildew fungi may cause bad tendering, but usually the cellulose is either not affected at all, or is attacked so slowly that in practice tendering is not appreciable.

The examination of cotton hairs by the Congo Red method[5] readily shows up damage to the cuticle, even before any loss of tensile strength can be detected. Table II shows the effect of three fungi acting on wet cotton under pure culture conditions. It will be seen that in this experiment only *Aspergillus niger* has produced any significant effect on the tensile strength. Nevertheless, even the slow growing *A. versicolor* is capable of cellulose decomposition, and if the duration of the experiment had been longer this species might have produced appreciable loss of strength.

Table II
Tendering of 32's Texas Yarn

	Control	*A. versicolor* 45	*Rhizopus nigricans* 84		*Aspergillus* [illegible]
		3 weeks	1 week	3 weeks	3 weeks
Ballistic test, work of rupture, gm/cm. per thread... ...	515	523	488	503	432
Single thread, breaking load, grams	240·1	247·9	240·1	234·8	196·3
Extensibility %	7·90	7·86	7·76	7·46	6·59
Congo Red examination ...	No damage	Slight	Slight	Slight	Considerably damaged

About 40 cultures were also grown on strips of filter paper sterilised in tubes containing 10 c.c. of the following medium recommended by Dubos[18].

Distilled water...	1 litre
Sodium nitrate, $NaNO_3$	0·5 g.
Potassium hydrogen phosphate, K_2HPO_4	1·0 g.
Magnesium sulphate, $MgSO_4,7H_2O$	0·5 g.
Potassium chloride, KCl	0·5 g.
Ferrous sulphate $FeSO_4$, $7H_2O$	0·01 g.

The degree of growth on the filter paper, though probably not an infallible criterion of cotton tendering power, gives a rough indication of the ability to decompose cellulose, and is indicated on Table I for the organisms tested.

The cellulose-destroying power of several of the fungi (e.g. *Aspergillus* 74, 31, sp. 43, etc.) has been confirmed by growth on cellulose-agar prepared in the usual way with filter paper reprecipitated from cuprammonium.

VII—IDENTIFICATION OF MILDEW FUNGI

The classification of the genera encountered is far from being completely worked out, and the worker who cannot devote considerable time to systematic work must be content with a general grouping of related species. Fortunately, the division into groups based on morphological features is found to agree fairly well with biochemical differences, and a rough classification is therefore sufficient for many purposes.

The structure and size of the sporing parts is the principal criterion in classification. Without careful control work, however, too great importance must not be attached to small differences in size, shape, or roughness of spores, since these details may vary slightly with the age of the culture and the medium.

Lactophenol is an excellent mounting medium, causing little or no distortion, and the original formula of Amann (already given, page T277) has been found quite satisfactory.

Aspergillus

This genus, thanks to the excellent monograph of Thom and Church[15], presents the least difficulty as regards classification. It can be divided into a number of natural groups; representatives of all these groups except the *Aspergillus clavatus* group are found on cotton goods, the *Aspergillus glaucus*, *versicolor*, *niger*, and *flavus* groups being the most common. Certain species referred to in this paper, and provisionally termed the *glaucus-fumigatus* group, have large oval spiny spores of the *glaucus* type, borne on conidiophores with terminal sterigmata of the *fumigatus* type.

A paper by Smith[13] describes a number of *Aspergillus* types found in cotton and gives descriptions which agree with those of Thom.

Pencillium

The classification of this genus is on a less firm basis. A number of species have been described by Thom,[14] but most of these do not appear to be common mildew forms.

In Westling's classification[19] the genus is divided into two groups, *Eupenicillium* and *Aspergilloides*, represented by the *camera lucida* drawings in Fig. 2. A summary of Westling's key is given by Mason,[10] but in this abridged translation identification appears to depend unduly on small differences in spore measurement and other characters subject to variation.

The large and well-illustrated monograph by Biourge[3] is the fullest account of the genus yet available*, but gives no simple key to the identification of species. Biourge's sub-division of *Eupenicillium* into *Bulliardium* and *Biverticillium*, and his emphasis on the zonation of cultures, require to be treated with caution, and should not be relied on for diagnostic purposes without considerable experience. On the other hand, the sugar-gelatin medium he describes under the name of "Raulin-Dierckx neutre" is invaluable in differentiating species by virtue of the remarkable range of colour production that it stimulates.

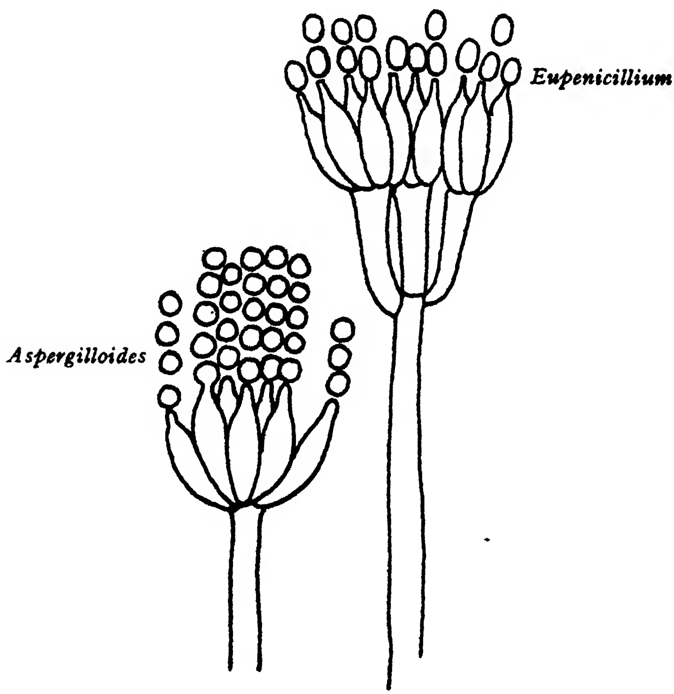

FIG. 2

In the present collection the *Penicillium* species have been provisionally grouped into series (*a*) to (*p*) of forms similar in general appearance and biochemical characters, though showing small individual differences, e.g. series (*b*) liquefies sugar gelatin media with the production of a yellow liquid, gives a yellow coloration in milk, and liquefies starch with the formation of acid; series (*c*) causes clearing of milk, and gives a yellow colour on starch paste. The majority appear to be related to *P. chrysogenum*, Thom, and *P. citrinum*, Thom; series (*a*) agrees well with *P. candidofulvum*, Biourge, and sp. 82 is almost certainly *P. Roqueforti*.

Until the nomenclature of this genus is more firmly established, caution would seem to be more desirable than too ready identification. It is still the practice of many workers to refer to any blue-green *Penicillium* as *P. glaucum*.

*Since the above was written a new and comprehensive study of this genus has appeared. (C. Thom, "The Penicillia," London, 1930, Baillière, Tindall & Cox.)

Other Genera

Of the other genera *Fusarium* is probably the most important as regards colour production, a number of species causing red and purple stains on cloth.

Mucor (including *Rhizopus*) is common in raw cotton, and some species are capable of producing tendering; but they do not develop freely at the humidities usually encountered by cloth, nor do they produce stains.

Cladosporium is a common cause of dark stains, as are *Stemphylium* and several other fungi belonging to the *Dematiaceæ*.

For the identification of the *Fungi Imperfecti*, Lindau's classification[9] is very useful; a summary and translation of the part relating to soil fungi is given by Waksman.[18]

Thanks are due to Mr. G. Smith, M.Sc., for a number of species isolated from cotton yarn and cloth. In the culture work recorded in this paper, considerable assistance has been received from Mr. G. R. Bates, B.Sc.

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20—COLOUR-BANDING IN FLEECES

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INTRODUCTION

Coloured sheep are not infrequently found in normal white-fleeced flocks. It is usual for the fleece or coloured portions of the fleece to show a uniform colour, but occasionally banding of the wool occurs. A banded wool is one in which there is an alternation between lighter and darker colours, an alternation which occurs more or less simultaneously over the whole fleece, and which results in the wool being traversed by well defined pigmented and non- pigmented bands. It is significant that in all the cases examined the outermost band formed by the tips of the wool was invariably coloured, and that, therefore, a sheep which produces a banded fleece always starts life as a coloured lamb. The simplest form of a banded fleece is produced when the coloured wool is traversed by a single white band, but in some fleeces there is a series of alternations and many bands are formed. There does not seem to be any limit to the number of bands which may be produced during the growth of the fleece, nor is the width of the bands the same, although the width of any particular band is more or less constant all over the body. In some cases the transition between band and band is clear-cut and well defined, but in others the outlines are fuzzy and indistinct. This is due to the fact that the individual fibres are not identical in their banding.

For the purpose of this study, five samples were used; four merinos (A, B, C, and D), and one coloured Hausa × Shetland cross (E). In each case they were from fleeces which had never before been clipped, so that the tips of the fibres were still intact. A macroscopic and microscopic analysis was carried out, and after separation of the fibres it was possible to classify four fibre types which occurred in every sample, whilst in the case of two samples there was a small proportion of an additional fifth type.

FIBRE TYPES

(a) Banded Fibres

The banded fibre is typical for its particular sample, and, except in one instance, constitutes the bulk of the fibres. It is always coloured distally and the alternation of the coloured and colourless bars is the same as that of the sample as a whole. Since, however, no two fibres are identical, there are individual variations in the width of the bands. In C, where the banding is unusually well defined, the extreme limits of variability of the middle white band lie between 0·2 cm. and 1·6 cms., although more than 80% of the fibres lie between 1·0 cm. and 1·6 cms. Gross irregularity of contour characterises the great majority of banded fibres, but it is impossible to attach any importance to the thickening of a pigmented portion when, further along the length of the same fibre, a coloured portion occurs which is thinner than any other part of the fibre, coloured or colourless.

The colour of the bands in any one fibre need not necessarily be the same, and there is often an appreciable difference between that of the distal band and the proximal, as in A and B, where many of the fibres show much diffuse pigment and less granular pigment distally, and a greater quantity of granular pigment proximally. When much diffuse pigment is present, the resulting

Table Showing Analysis into Fibre Types

Sample	Description of Sample	Fleece Growth	No. of Bands	Colour of Bands		Width of Bands	Fibre Type: Banded	Fibre Type: Coloured	Fibre Type: White	Fibre Type: Intermittent	Fibre Type: Bipartite a	Fibre Type: Bipartite b	Total
A	South Australian Merino. Whole fleece, (i) shoulder, (ii) belly.	12 months 12 cms.	3	Distal Median Proximal	Brown White Dark grey	cms. 3·7 5·5 3·4	i, 36 ii, 57	— 32	54 9	6 2	2 —	2 —	100 100
B	Western Australian Merino. Portion of skin.	9 months 10 cms.	9 3 major, with imposition of narrow bands in median bar	Distal Median Proximal	Light brown, with very pale tips White Dark brown (The narrow bands which traverse the median white are brown)	5·5 2·9 2·4 0·2	72 (a:40) (b:32)	6	8	14	—	—	100
C	South Australian Merino. Portion of skin.	9 months 8 cms.	3	Distal Median Proximal	Reddish brown White Reddish brown	4·54 1·05 2·23	86	9	3	2	—	—	100
D	Cape Merino. Samples i and ii.	12 months 8 cms.	6 with indication of 7th proximally	Distal Median Proximal	Dark brown Narrow white Dark brown White Dark brown White	2·4 0·1 0·1 0·3 0·2 5·1	i, 94 ii, 90	3 2	3 1	— 3	— 4	— —	100 100
E	Coloured Hausa × Shetland cross. Sample.	10 months 12 cms.	5 with indication of 6th proximally	Distal Median Proximal	Black, with dark brown tips Grey Black Grey Black	7·4 1·8 0·8 1·2 0·8	67	26	3	4	—	—	100

colour is always lighter and brighter. In B it is necessary to define two types of banded fibre—(*a*) with proximal and distal coloured bands and clear median portion, and (*b*) complete with distal and proximal coloured bands and with three additional coloured bands running through the median colourless one. In 100 fibres, of which 72 were banded, 40 were of the (*a*) group, and 32 of the (*b*) group. Observation proves that an even smaller percentage of the (*b*) group fibres would have been sufficient to make the extra median bands apparent in the fleece.

It is not the proportion of banded fibres which defines the ultimate character of the fleece, for, whilst a few such fibres are sufficient to give a banded appearance to an otherwise white wool as in A (i), the effect of a large number of banded fibres is almost annulled by the presence of a few all-coloured fibres as in A (ii), and in some cases these are sufficient practically to obliterate the appearance of banding. In B, C, and D, where the banding is very distinct and colour contrasts are great, there are few completely colourless or completely coloured fibres, but in E, where the lighter bands are grey as opposed to the darker ones which are practically black, the dullness of the lighter bands is accounted for by the presence of many coloured fibres which detract from the white effect produced by the banded fibres. It is possible that many apparently self-coloured wools are really banded, and that the banding is masked by the aggregation of the coloured fibres. This, of course, could only be determined after an analysis had been completed.

Although, to the naked eye, the transition between the bands of the fibre is distinctly abrupt, microscopically there is a definite transition zone, highly variable in extent. In some cases there is a quick transition between pigmented and non-pigmented portions within a space of about 200 μ, whilst in others the transition is so gradual as to be almost imperceptible, and the transition zone exceeds 1,000 μ. In many fibres the lighter bands are not really colourless, but contain a diminished quantity of granular pigment, or in some cases merely diffuse pigment. When the coloured bands of a banded fibre are lighter than usual, it is sometimes found that there is a tendency for the pigment granules to lie along one side of the fibre only. This condition is specially prevalent in A and E.

(b) White Fibres

These were found to consist of two types, the one completely lacking pigment, and the other containing it in such small quantity as not appreciably to colour the fibre. In the pigmented white fibres, the pigment always takes the form of minute scattered granules, and the diffuse type is never seen. It is significant that a relatively large proportion of white fibres, such as occur in A (i), is not sufficient to obliterate banding, although it considerably modifies the colour of the distal and proximal bands, making them much lighter.

(c) Coloured Fibres

Under this heading are grouped all those fibres which are completely pigmented from tip to base. They vary in colour from lightest to darkest brown, and in E practically all the coloured fibres are nearly black. A few coloured fibres were found which gradually faded from dark brown at the tip to lighter fawn proximally. In both A (ii) and E, the proportion of coloured fibres to the rest of the sample is relatively greater than that elsewhere, and the colour of the samples themselves is proportionately darker. In A (ii)

these coloured fibres practically obliterate banding, whilst in E they darken the lighter bands to a dull grey colour.

There is considerable variation in the thickness of coloured fibres, the coarsest of them being thicker than the thickest fibre of any other type. When pigment deposition is unusually heavy, even a casual examination reveals irregular differences in thickness along the length of the fibre, and often the darker the fibre the greater its thickness. In D the all-coloured fibres are very much thicker distally, where pigment production is more or less uniform for the whole fleece, than proximally, where a distinct refinement is apparent.

(d) Intermittent Fibres

An intermittent fibre is one which is banded, but irregularly so, and the alternation and number of the coloured and colourless bars differ to a greater or lesser extent from that of the banded fibres.

In C, the proximal and distal bands of the intermittent fibres are coincident with those of the banded fibres, but in addition, the median colourless bar is interrupted. This, however, is a somewhat extreme case, and such a close correlation was not observed anywhere else.

Many of the intermittent fibres are hair-like in appearance, and there is the greatest diversity in the colour of the pigmented parts. The percentage of these fibres is small, even in B where the largest number occurs.

(e) Bipartite Fibres

These are limited in their distribution and occur only in A and E. They exhibit the simplest of all types of banding, and there is but one colour alternation. Such fibres are pigmented distally and colourless proximally (*a*), or *vice versa* (*b*), and it is as usual to find the one type as the other. The line of demarcation between the bands is frequently found to lie about half-way along the fibre, but this is not a constant characteristic.

TRICHORRHEXIS

This is a pathological condition which has been recorded for various types of hair. Small nodular swellings are developed at intervals along the length of the fibre and eventually the fibre breaks apart at these points. A condition approximating to that of trichorrhexis was apparent in many of the parti-coloured fibres, and the transition zone between bands was often marked by one of these nodular swellings. It is probable that the facility with which such fibres fracture is in some measure due to this fact.

As far as could be ascertained from this study, there is little association between fibre colour and fibre structure.

DISCUSSION

It is apparent that notwithstanding the occurrence of many forms of banded wool, the phenomenon is in all cases essentially similar. Although all the fibres do not undergo a change at the same time, the majority do so with, however, considerable individual variation. This affects the delimitation of the bands of the fleece and when their outline is fuzzy and indistinct, it is directly due to this variable banding of the individual fibres.

The mechanism underlying the banding process is not yet known, but banding itself is a condition which has been observed in many animals besides sheep, such as rabbits, guinea-pigs, rats and mice. Here the fibres are seldom sufficiently similar in their banding to give the bands of the coat

as a whole a clearly defined outline. Dry (1928), working on rats and mice, found that adjacent follicles may at the same moment be producing black pigment in the one case and yellow in the other.

Since all five sheep from which the samples were taken started life as coloured lambs, there is reason to believe that the sheep producing the banded fleece is genetically coloured.

Roberts and White (1930) show that the ordinary white fleeced condition depends upon the presence of a dominant white factor in the absence of which the fleece is coloured. These writers discuss, as a theoretical possibility, the existence of a recessive white in sheep. The condition described in this paper would appear to point to the same conclusion, since the lack of pigment in the light bands is in all probability not due to an inhibiting factor.

Onslow (1915) showed that in rabbits there were two types of white, a dominant and a recessive. The former is due to the presence of an inhibitor of the pigment producing oxidase, whilst the latter is caused by the absence of either or both of the chromogen and oxidase constituents of the pigmentary system. Since the pigmentary system in a sheep with a banded fleece is at certain periods normally functional, in that pigment is produced, it is possible that the light banding is due to the periodic absence of either the chromogen or of the catalytic enzyme.

A type of banding is described by Wassin (1928) to which he gives the name agouti. This banding is of a genetic nature and involves a light ring towards the tip of dark fibres. In the actual fleece, however, agouti banding was found only in new-born lambs, and was never observed in the adult. Similarly, Roberts and White (1930) describe a condition in the coat of some of their coloured experimental lambs in which the tips of a proportion of the fibres are golden brown in colour. In both these cases, however, the fibres affected are birth-coat fibres, together with short, stiff hairs which are, in all probability, derived from the outer coat. Apart then, from the fact that parti-coloured fibres are involved in all these cases, the banding described in the present paper appears to be an entirely different phenomenon.

Since the banding takes place with such regularity over the whole fleece, it seems likely that it is in some way related to a definite physiological condition of the body as a whole, although in all probability it is primarily genetic in origin.

SUMMARY

(1) Banded fleeces in which a dark wool is traversed by one or more light bands are occasionally found in coloured sheep. The sheep which produces such a banded fleece always starts life as a coloured lamb. Five samples were available and are described.

(2) Analysis shows that in every case the phenomenon is essentially the same. In all samples four fibre types occurred, and in two there was an additional fifth type, but in small proportion.

A—Banded fibres in which the bands correspond with the banding as seen in the fleece, although with considerable individual variation.

B—Coloured fibres.

C—Colourless fibres.

D—Fibres showing intermittent pigmentation.

E—Bipartite fibres—

(i) Pigmented distally, colourless proximally.

(ii) *Vice versa.*

Comparatively few banded fibres are sufficient to form a light band, if the rest of the fibres are colourless, but on the other hand, the light band is almost invisible if coloured fibres are present in sufficient numbers. It is suggested that some apparently self-coloured wools may really be banded, but that the banding is masked.

(3) Diffuse and granular pigment were observed and occurred either together or separately. The transition zone between the bands of a fibre varied considerably and in some cases there was an abrupt cessation of pigment deposition, whilst in others the reduction in the amount of pigment was so gradual as to be almost imperceptible.

(4) Comparison is made with colour banding in other mammals, and there is a brief reference to the genetics and physiology of the condition.

ACKNOWLEDGMENTS

The work described in the above paper was carried out in the Biology Department of the British Research Association for the Woollen and Worsted Industries, Torridon, Leeds, by kind permission of Professor F. A. E. Crew, of the Department of Animal Genetics, University of Edinburgh, under whom, during the period covered by this investigation, the writer has been pursuing a course of study. She is deeply grateful to Mr. J. A. Fraser Roberts, Head of the Biology Department, for his generous advice and helpful criticism, and to Dr. S. G. Barker, Director of Research of the Association. She is indebted to Mr. W. C. Miller, of the Department of Animal Genetics, Edinburgh, who kindly provided one of the samples; to Professor R. G. Stapleton, of the Welsh Plant Breeding Station, Aberystwyth; to Mr. H. Frank Pennefather, of Sydney, New South Wales, who also provided material; and to Mr. F. Hainsworth, of the Department of Printing, Leeds Technical College, for his very kind assistance in preparing the photographs.

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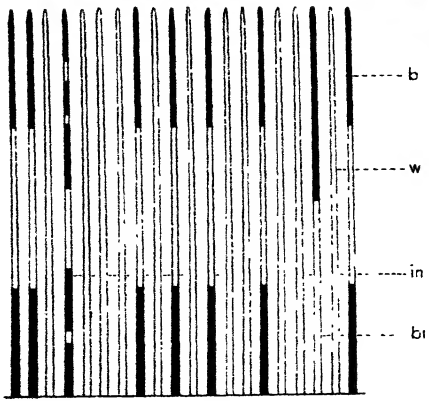
KEY TO LETTERING ON PLATES

b	banded
w	white
in	intermittent
bi	bipartite
c	coloured

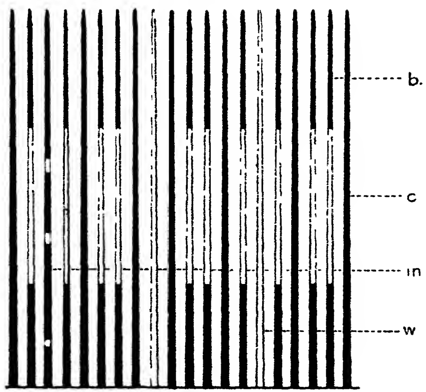
PLATE I

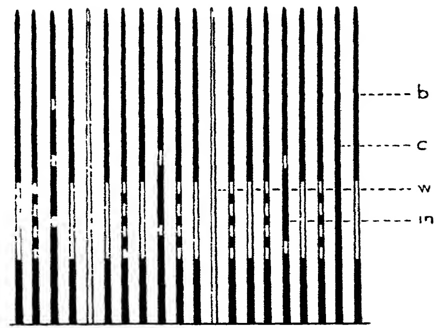
PLATE II

PLATE III



A

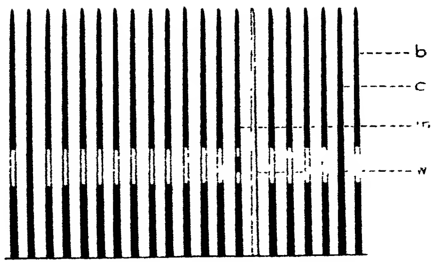




B

Plate IV

Plate V



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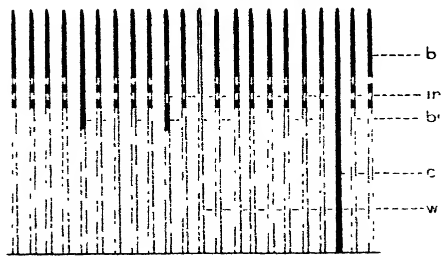

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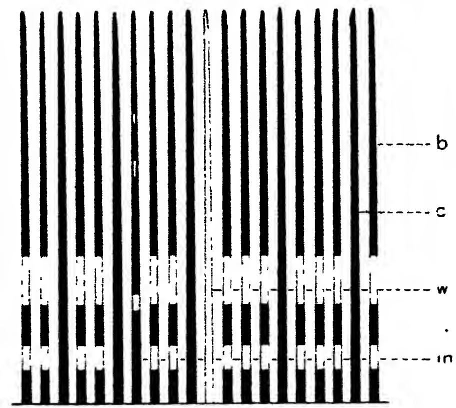

E

THE JOURNAL OF THE
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TRANSACTIONS

21—THE LENGTH CHANGES OF COTTON HAIRS IN SOLUTIONS OF CAUSTIC SODA

By Mary A. Calvert, B.Sc.
(The British Cotton Industry Research Association)

I—INTRODUCTION

Many observations have been made on the decrease in length of cotton materials on immersion in caustic soda solutions, and "shrinkage curves" have been constructed to show the relation between the loss of length and the concentration of alkali. It was pointed out by Willows, Barratt, and Parker[7] that the change in length of a yarn depends on several factors, such as the change in length of the component hairs, the change in their section, and the slipping or accommodation of individual hairs in the thread. The effects of these factors cannot be easily separated, and their relative importance varies with the structure of the yarn. Willows, Barratt, and Parker therefore proposed a more fundamental study in which they observed the length changes in caustic soda solutions of the component unit of cotton threads, the single cotton hair, and they constructed a shrinkage curve for a particular set of hairs investigated under certain defined conditions. These authors showed clearly in their paper that they realised the necessity for a further study of the behaviour of hairs under a wider range of conditions than was covered by them. It was from the beginning probable that difficulties would arise in generalising from shrinkage measurements made on single hairs similar to the difficulties previously encountered with yarns, and for a similar reason. The hairs themselves possess a structure far finer, but almost certainly more complicated than that of a spun yarn, and to a greater or less extent the shrinkage of cotton hairs must be controlled by their structure, which is itself variable, as well as susceptible to modification by mechanical and chemical treatments.

The changes in length of cotton hairs in caustic soda solutions of various concentrations have also been studied by Collins and Williams.[4] These authors submitted hairs to *successive* treatments with alkali solutions of progressively increasing or decreasing concentrations, and obtained curves for the relation between the dimensions of the hairs and the concentration of the caustic soda under these conditions. Owing to the irreversibility of the dimensional changes that occur, these results are not comparable with those recorded by Willows, Barratt, and Parker for the shrinkage of hairs in single solutions, or with those now to be described.

This paper presents an investigation of the shrinkage of single cotton hairs not previously submitted to a swelling treatment, when immersed in caustic soda solutions of definite concentrations under a wider range of conditions than has been covered by previous workers.

The next section gives a review of the results obtained, which are not so simple as would be expected from structures less complex than the cotton hair. The experimental methods and tables of data are given in Section III.

II—REVIEW OF RESULTS

Free and Restricted Shrinkage

The measurements are confined almost entirely to the length changes of hairs immersed in caustic soda solutions, and the effect of tension on these changes. In the technical processing of cotton material the hairs can shrink only against the restraint imposed by neighbouring hairs bound to them in the spinning of the yarn or the weaving of the fabric, so that a study of the behaviour of individual hairs under diverse conditions of tension is evidently of fundamental importance. The following have been the main points of investigation—

I—Shrinkage of scoured hairs.
- (*a*) Under no load ("Free" shrinkage).
- (*b*) Under loads applied after shrinkage under no load ("Free" shrinkage measured under a load).
- (*c*) Under loads maintained throughout the shrinkage ("Restricted" shrinkage).

II—Shrinkage of raw hairs.
Under conditions (*a*), (*b*), (*c*) above.

III—Shrinkage of hairs extracted by chloroform.
Under condition (*c*).

IV—Shrinkage of raw hairs mechanically treated.
Under conditions (*a*) and (*c*).

In order to facilitate the more important comparisons to which attention will be directed, the corresponding shrinkage curves for one of the cottons examined (No. 226) have been collected for convenient review on the accompanying plate; the individual figures on this plate will be referred to as the text demands. (See Plate I, Figs. 2, 6, 8, 13, 14, 16).

A difficulty arises in the purely experimental measurement of free shrinkage under no load. It is a simple matter to isolate an individual hair from its neighbours and to allow it to shrink freely in caustic soda solution without any external restraint, but in order to measure its length the hair must be straightened, and this necessitates the application of a small tension in the direction of its length. The free shrinkage observed experimentally corresponds therefore to unrestricted shrinkage of the hair, but the measurement is made under a small tension applied subsequently. This tension produces a slight increase in the length of the hair, with the result that the observed shrinkage is slightly less than the true free shrinkage measured ideally under no tension. From a number of experimental observations of free shrinkage made on the same hair and measured under small but different tensions, it is possible to determine by extrapolation the free shrinkage under no tension. This is the principle used in determining the free shrinkage curves of cotton hairs under no load, several examples of which are given in this paper. The total change in length that is observed when a hair is first allowed to shrink under no external restraint and is then submitted to a lengthwise tension—the free shrinkage measured under that tension—is evidently the resultant of two quantities—the free shrinkage under no tension and the stretch produced in the fully shrunk hair by the application of tension.

As distinct from "Free Shrinkage" curves, this paper illustrates a number of curves described by the words "Restricted Shrinkage." These have been obtained by allowing hairs to shrink against a definite restraint imposed externally in the form of a small load attached to the hair; the shrinkage is then measured under the same load, the experimental method thus being

very simple. It is important to distinguish between the *free* shrinkage of cotton hairs measured, for example, under a 10 mg. load, and their *restricted* shrinkage under the same load. By the former method no constraint is placed on the shrinkage, but the measurement is made under a 10 mg. load, whilst by the latter, shrinkage must take place against a 10 mg. load, which resists the shrinkage, and the length measurement is made under the same load. The importance of this distinction will become evident in the sequel.

Free Shrinkage Curves of Scoured Cotton Hairs

The results to be described were obtained from hairs of Egyptian (Sakel) Cotton (No. 226), that had been boiled in the form of a combed yarn for 6 hours with 1% caustic soda solution at 20 lb. excess pressure, and subsequently separated from the yarn by untwisting. Fig. 1 shows the free shrinkage of these hairs under no load; the per cent. decrease in length of the air-dry hairs on direct immersion in one caustic soda solution is plotted vertically, and the concentration of the alkali horizontally, for the range of solutions 11·1% to 26·8%.* Each point on the curve is the average value obtained from the observation of 50 individual hairs; this applies to all other curves given in the paper. The curve for free shrinkage under no load is simple in form, and shows a well-marked maximum shrinkage for hairs immersed in 13·3% caustic soda, as near as the number of solutions used permits this maximum to be defined.

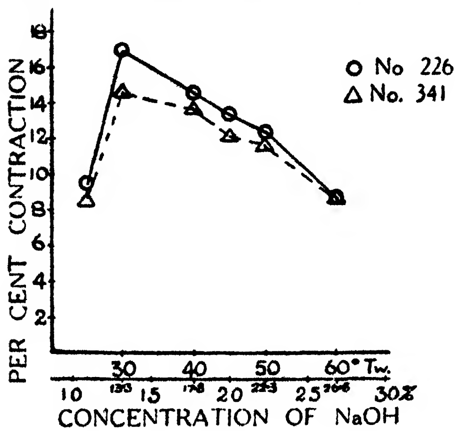

FIG. 1

Fig. 1 also shows the curve for free shrinkage under no load obtained for another cotton (No. 341), also of Egyptian growth. These hairs were taken direct from the seed and boiled for 6 hours with 1% caustic soda at 20 lb. excess pressure. The curve closely resembles that obtained from No. 226, although the shrinkage in 13·3% caustic soda is less. Curves are given in Fig. 2 (see Plate) for free shrinkage of the scoured cotton No. 226, measured under loads of 8, 20, 42, 100, and 130 mg. The shrinkage values measured under a load of 500 mg. are given in Table II, but are omitted from the graph for convenience of spacing. The loads were applied slowly by small increments. The curves show shrinkage values lower than those for free shrinkage under no load by an amount that corresponds at each point to the extension produced in the fully shrunk hair by subsequent application of the load. The maximum at 13·3% becomes less marked as the load increases, and the addition of a load has least effect in the most concentrated solution.

*Concentrations are expressed in this paper as weight percentages (grams of caustic soda in 100 grams of solution). They were controlled by titrating the solutions with standard acid, and not by density determination. In the figures and tables the solutions are described alternatively by their densities in degrees Twaddell, this being convenient for the comparison of results with those of other British workers on the same, or a related, subject. Again, for convenience, the solutions used were selected according to their densities in degrees Twaddell, and this accounts for the very arbitrary appearance of the concentration values; 11·1% and 26·8% caustic soda solutions correspond, for example, to densities of 25° and 60° Twaddell respectively (*cf.* Table XVI, Section III).

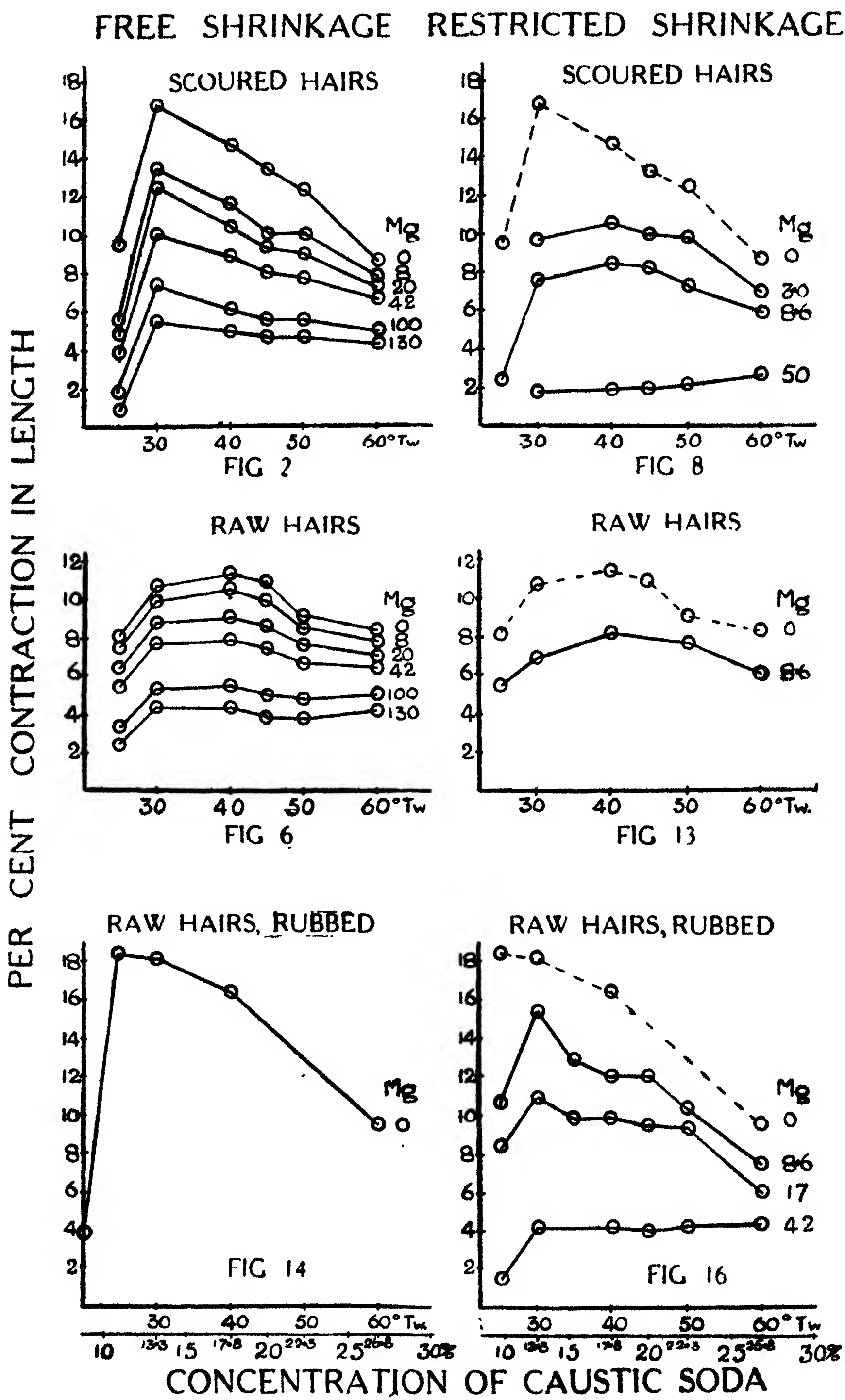
FREE SHRINKAGE
RESTRICTED SHRINKAGE
PER CENT CONTRACTION IN LENGTH
SCOURED HAIRS
Mg
0
8
20
42
100
130
FIG 2
SCOURED HAIRS
Mg
0
30
86
50
FIG 8
RAW HAIRS
Mg
0
8
20
42
100
130
FIG 6
RAW HAIRS
Mg
0
86
FIG 13
RAW HAIRS, RUBBED
Mg
0
FIG 14
RAW HAIRS, RUBBED
Mg
0
86
17
42
FIG 16
30
40
50
60° Tw
10
15
20
25
30%
CONCENTRATION OF CAUSTIC SODA

PLATE I

In obtaining the shrinkage values already given the load is applied in such a way that each hair is subjected to a load increasing gradually from 0 to 500 mg., the shrinkage of the hair being noted under each of the six loads mentioned. By employing an entirely different technique it is possible to subject the hair suddenly to any given single load. Fig. 3 (b) shows the shrinkage curves obtained from this "rapid loading," and compares them with those already obtained from "slow loading," Fig. 3 (a). In "rapid

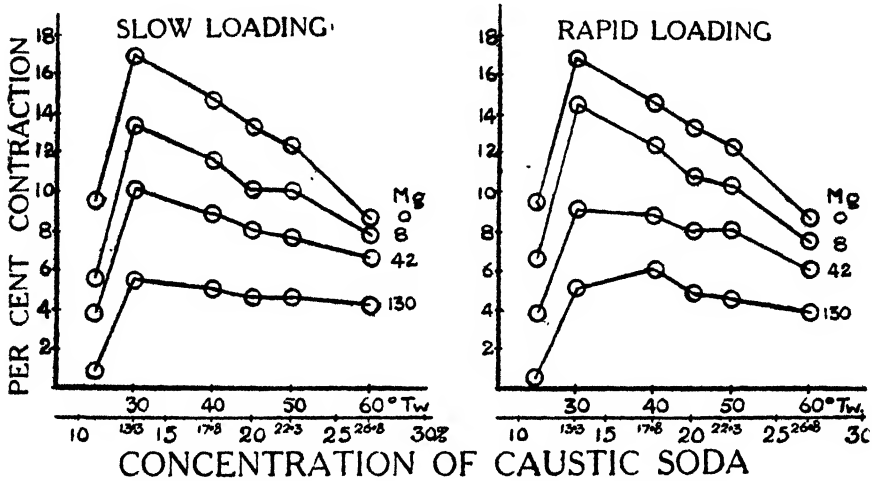

FIG 3a FIG 3b

loading" each point on each curve represents the mean shrinkage of a distinct set of 50 hairs, so that to obtain, say, 6 points on 3 curves, 900 hairs have been used. During "slow loading" one set of 50 hairs for each concentration was subjected to gradually increasing tension, so that to obtain, say, 6 points on 3 curves, only 300 hairs were used. Under the latter conditions, therefore, the effect of any chance hair showing abnormal shrinkage will persist under all loads, and one curve is to a certain extent dependent on another. In view of this fact and of the fact that a totally different apparatus was used in the two methods, the two sets of curves shown in Fig. 3 are in good agreement. The general similarity between the two sets of curves suggests that the rate of loading does not greatly affect the final shrinkage, but the data are insufficient to enable a more definite conclusion to be drawn from them on this point.

Free Shrinkage Curves of Raw Cotton Hairs

Fig. 4, curve 1, shows the free shrinkage under no load of hairs from raw cotton No. 226, which had not received any scouring or other chemical process of purification. It is compared with the corresponding curve—already described and reproduced in broken line (curve 2) in Fig. 4—obtained for hairs of the same cotton after alkali boiling. The shrinkage of the raw hairs is much less than that of the scoured hairs in the same concentration of caustic soda within the range 13·3% to 22·3%, the difference being greatest in 13·3%; the maximum that occurs at this point in the curve for free shrinkage of the scoured hairs is not present in the curve obtained with the raw hairs.

Fig. 5, curve 1, is the curve for free shrinkage under no load of the raw cotton No. 341, the behaviour of which after scouring has also been described

and is represented by the broken line (curve 2) in the same figure. Here again the raw hairs shrink to a much smaller extent than the scoured over a wide range of alkali concentration, and they do not show a maximum shrinkage in 13·3% solution as did the scoured hairs. The only generalisation it seems possible to make from the results of measurements on the two raw cottons investigated is that in concentrations of alkali between 13·3% and 20·1% the shrinkage is approximately constant. The marked difference in form between the free shrinkage curves of raw and scoured cottons should be emphasised.

Free shrinkage curves for the raw cotton No. 226 measured under loads of 8, 20, 42, 100, 130 mg., are shown in Fig. 6 (Plate). Here, as for the scoured hairs, there is a gradual flattening out of the curve as the load is increased. These data, together with those already shown in Fig. 2, are presented in a different form in Fig. 7 (i) and (ii). Per cent. shrinkage in caustic soda solution is plotted against the applied load for loads up to 130 mg., the higher load of 500 mg. being omitted in order to avoid obscuring the effect of low loads by compression of the horizontal scale. These curves may be conveniently used to determine, not only the extension produced by the application of a constant load, but also the load necessary to produce a given extension of the freely shrunk hair.

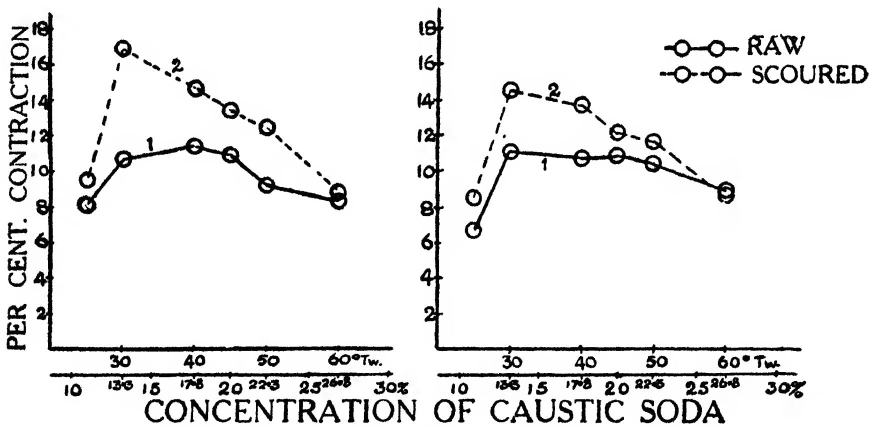

FIG 4
No. 226

FIG 5
No. 341

Restricted Shrinkage Curves

Restricted shrinkage curves are obtained by allowing hairs to shrink against a constant load and measuring the change of length under the same load. Fig. 8 (Plate) gives the restricted shrinkage curves for the scoured cotton No. 226 under loads of 3 mg., 8·6 mg., and 50 mg., whilst the curve for free shrinkage under no load is shown for comparison by the broken line. Each point on each restricted shrinkage curve represents a different set of 50 hairs. The restricted shrinkage curves naturally fall below the curve for free shrinkage under no load, from which they differ markedly by the absence of the 13·3% maximum. It is remarkable that, provided free shrinkage is not allowed, a load of 3 mg. per hair is capable of removing entirely this very characteristic peak. The curves for restricted shrinkage under low loads (3 and 8·6 mg.) show a flat portion between 13·3% and 22·3%, a range of concentration over which the shrinkage alters little. The curves are similar

in form to the curves for *free* shrinkage of *raw* hairs (Fig. 6, Plate). Under 50 mg. load the shrinkage increases steadily over the whole range from 13·3 to 26·8 per cent.

Fig. 9, curve 2, shows the restricted shrinkage of scoured cotton No. 341 under 3 mg. load. Here again the shrinkage—unlike that under no load (curve 1)—is approximately constant over the range of concentration from 13·3% to 22·3%, and the shrinkage values, except in 26·8% solution, are identical with those for *free* shrinkage of the *raw* hairs under no load (curve 3).

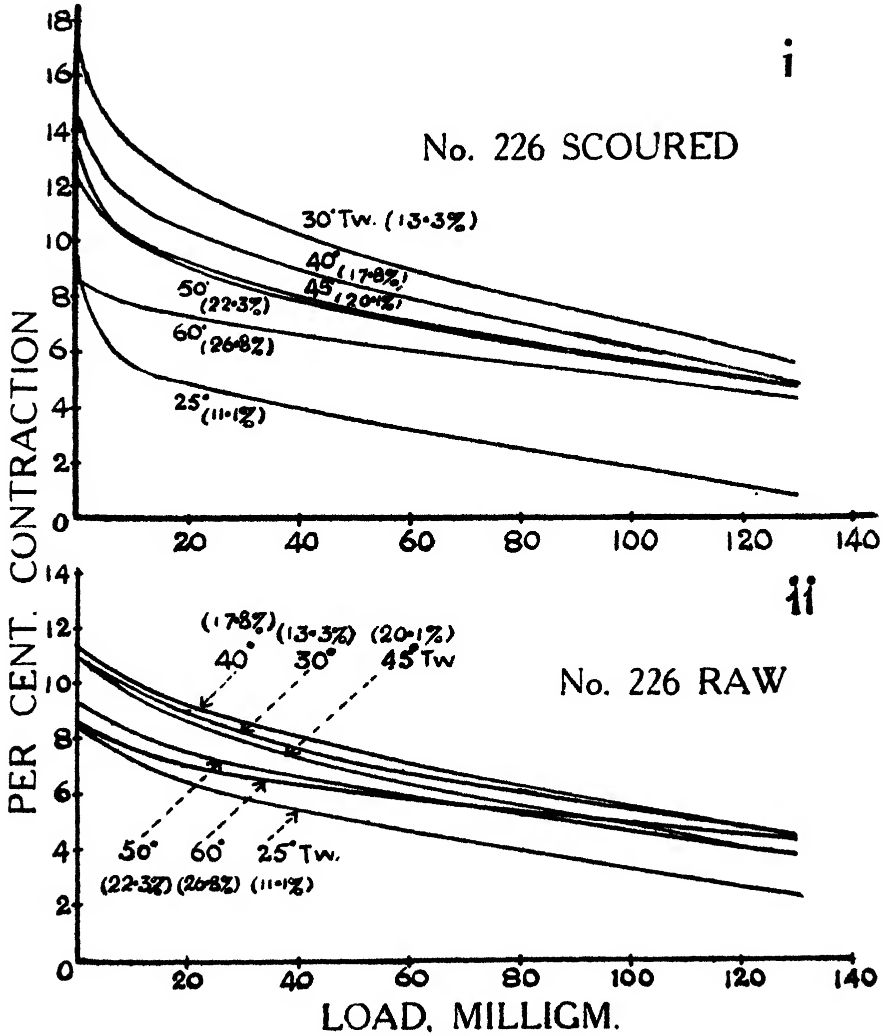

FIG. 7

It can now be seen that a great difference exists between the restricted shrinkage under a given load and the free shrinkage measured under the same load. In order to illustrate the difference, Fig. 10 compares the restricted shrinkage of scoured cotton No. 226 under a load of 50 mg. (curve 1) with the free shrinkage measured under the same load (curve 2), the free shrinkage measured under 50 mg. having been read from Fig. 7.

It is well known that the tension necessary to prevent the shrinkage of cotton yarns and fabrics in caustic soda solutions is much less than the tension necessary to recover their original dimensions when shrinkage has once been permitted. The similar behaviour of cotton hairs is well shown in Fig. 10. In 13·3% caustic soda, for example, a load of 50 mg. permits shrinkage only to the extent of 2%, whilst if the hairs are first allowed to shrink freely in the same concentration of alkali and a load of 50 mg. is then applied, they still remain shorter by nearly 10% of their original length.

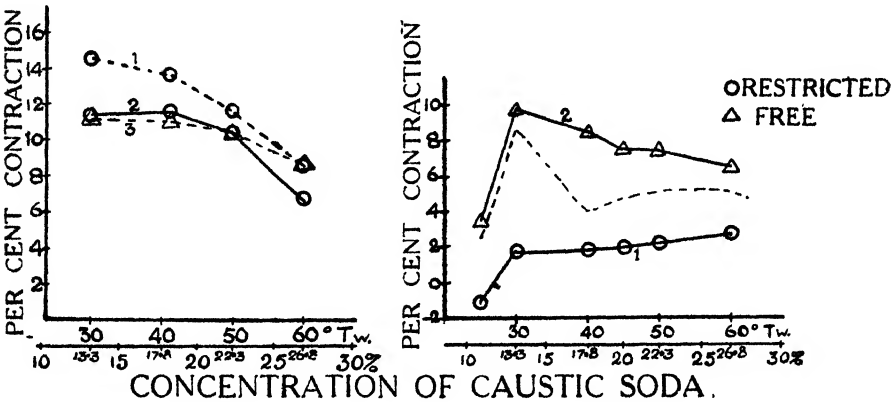

FIG 9 FIG 10

The curve shown in broken line (Fig. 10) is the curve for shrinkage under 50 mg. obtained by Willows, Barratt, and Parker[7] for hairs from a combed Egyptian sliver boiled for 1 hour in 2% solution of sodium carbonate. These authors worked under conditions described in this paper as those of "Restricted shrinkage," but their curve lies roughly halfway between the "free" and "restricted" shrinkage curves now obtained with cotton No. 226.

Fig. 11, curve 1, is the curve for restricted shrinkage of the raw, and curve 2 of the scoured, cotton No. 226, both under 8·6 mg. load; whilst curves 3 and 4 shown in broken line are the curves for free shrinkage of the raw and scoured cottons respectively under no load. A comparison of the curves suggests that although, in what has been called "free shrinkage," the raw hairs are subjected to no external restraint, some internal resistance, from which scoured hairs are free, is imposed upon their shrinkage, and has the same effect upon their behaviour as the direct application of a load has on the behaviour of scoured hairs.

Shrinkage of Hairs Extracted by Chloroform

Fig 12 shows the curve for restricted shrinkage under 8·6 mg. of the raw cotton No. 226 after it has been extracted with chloroform. The curve for the same cotton before extraction is shown in Fig. 13 (Plate) and by the broken line in Fig. 12; it is evident that shrinkage has not been increased by the removal of fats and waxes.

The Severity of the Scour

The effect of various conditions of kier boiling on free shrinkage in caustic soda solutions has been tested for raw cotton No. 226. The cotton was boiled in the form of yarn. Hairs were subsequently separated from the yarn and free shrinkage measured under 8·6 mg., determined in 13·3% caustic soda, since it is in this concentration that the effect of scouring on shrinkage has

been found to be most marked (*c.f.* Figs. 4 and 5). The conditions of boiling were as follows—

(1) A boil in water for 6 hours, under atmospheric pressure.
(2) A boil in 1% sodium carbonate (Na_2CO_3) for 6 hours under atmospheric pressure.
(3) A boil in 1% caustic soda under 20 lb. per sq. in. excess pressure for 6 hours.

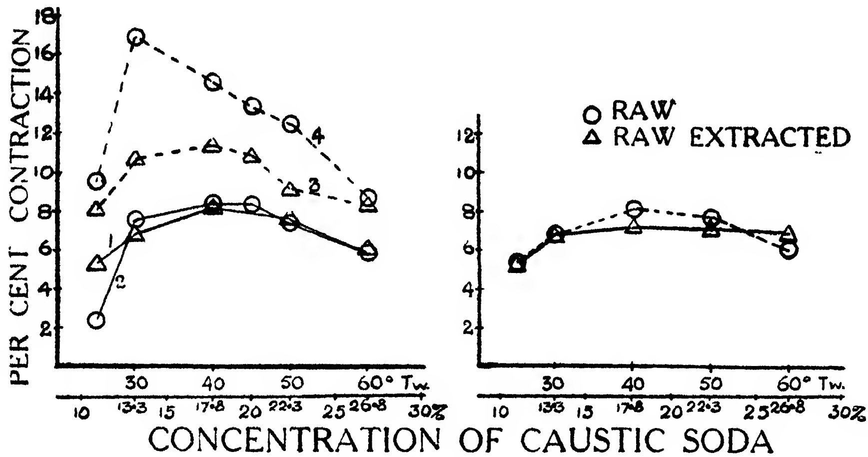

FIG 11 FIG 12

It may be seen from Table V that these differences in severity of treatment do not produce corresponding differences in shrinkage, the water-boiled hairs showing a shrinkage as high as that given by hairs from yarn caustic-boiled under pressure.

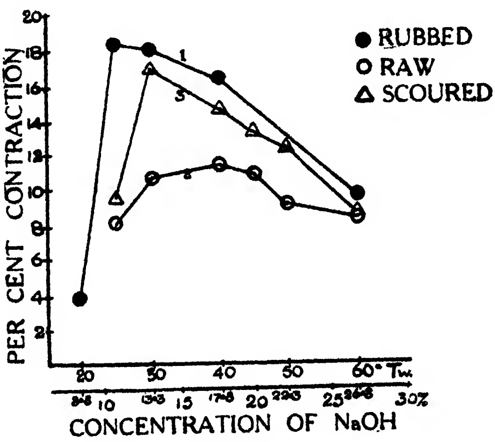

FIG. 15

Shrinkage Curves of Rubbed Hairs

Hairs of the raw cotton No. 226 were rubbed with fine emery paper in such a way that subsequent staining with Congo Red[1] proved the cuticle to be partially or completely stripped.

The free shrinkage under no load of the raw hairs after rubbing is shown in Fig. 14 (Plate) and in Fig. 15, curve 1, while curve 2 (Fig. 15) shows the

free shrinkage of the same hairs before rubbing, and curve 3 the free shrinkage of scoured hairs. The mechanical treatment has greatly influenced the behaviour of the raw hairs, having, for example, almost doubled their shrinkage in 13·3% solution and more than doubled it in 11·1%, so that the maximum that occurs at about 13·3% for the scoured hairs is located nearer 11·1% for the mechanically-treated raw hairs; there is thus a continuous shift in the position of the maximum on passing from rubbed to scoured and from scoured to untreated raw hairs. The scouring process and the mechanical injury have produced similar effects upon the shrinkage of the raw hairs, but to a different degree.

Fig. 16 (Plate) shows the restricted shrinkage curves for the rubbed hairs under loads of 8·6, 17, 42 mg. Here, as for the scoured hairs, the effect of 8.6 mg. is remarkable. Under this load the peak at 11·1% is entirely removed and the curve is similar in form to the curve for free shrinkage of scoured hairs under no load (Fig. 2).

The restricted shrinkage of rubbed hairs under a small load is therefore comparable with the free shrinkage of scoured hairs under no load, whilst the restricted shrinkage of scoured hairs under a small load is comparable with the free shrinkage of raw hairs under no load.

These observations support the view that some structural resistance is imposed upon the shrinkage of raw hairs, but they also show that the scoured hairs are by no means free from this restraint, although they are freer than the raw hairs. It is natural to assume that the restraint on the free shrinkage of the raw hair, and to a less extent of the scoured hair, is imposed by the cuticle, or by the primary wall. Individual hairs of the same cotton immersed in the same solution of caustic soda show a wide range of shrinkages, which necessitates the statistical treatment of the problem. If, as seems not improbable, individual hairs differ in the development of their cuticle or of their primary wall, the great hair to hair variability in shrinkage receives an adequate explanation in the light of the results described. Willows and Alexander,[6] in their study on the changes in cross sectional area of cotton hairs in caustic soda solutions, suggest that the variability observed by them might be due to "differences in the ripeness or development of the hair." This explanation is not at present capable of a direct experimental check, but it has not been found possible to relate the variations of shrinkage experienced by different hairs in the same solution with variations in any other single hair characteristic, such as the original length or wall thickness of the hair, or the number of convolutions in it.

The change in length experienced by a loaded hair when immersed in a caustic soda solution is the resultant of the *increase* in length consequent on the removal of convolutions, and the *decrease* in length produced by the swelling action of the alkali. From the available data, it is not possible to separate these two effects, but Collins and Williams[4] have shown that the increase in length of a loaded hair when immersed in water and in *dilute* caustic soda solutions is closely related to the change in the number of its convolutions. Since in caustic soda solutions above about 12% in concentration the removal of convolutions is complete, the increase in length due to this cause should be related to the total original number of convolutions. No close correlation has been observed, however, between the shrinkages of different hairs in such a solution and the number of convolutions that they originally contained; it is therefore not possible to explain the variability in shrinkage solely as a result of the variability in convolution number.

It is of interest to compare the shrinkage curve of rubbed cotton hairs with those obtained by Nodder and Kinkead[5] for linen and ramie fibres which are devoid of cuticle. The bast fibres show a single and highly accentuated maximum shrinkage between 8·8% and 11·1%, and cotton hairs resemble them in this respect only when the external layer of the hair wall has been removed or damaged by mechanical treatment. Another observation of these authors that appears to be significant in the light of the above considerations is that the variability of shrinkage from one bast fibre to another is small, so that measurements made, for example, with no more than ten ramie fibres were sufficient to fix adequately the position of a point on the shrinkage curve.

The Width Changes of Raw, Scoured, and Mechanically-treated Hairs

A discussion of width changes would be out of place in the present paper, but for the sake of some completeness it should perhaps be added that measurements of width by a technique already described[2] have shown that the increase of width in caustic soda solutions of scoured and of rubbed hairs is greater than that of raw untreated hairs, and that if raw hairs are rubbed before immersion in the alkali the width curve is transformed from one giving a relatively constant value from 13·3% onwards to one showing a highly accentuated maximum in the region of 11·1% caustic soda. These differences are illustrated in Fig. 17; curve 1 shows the mean hair width of

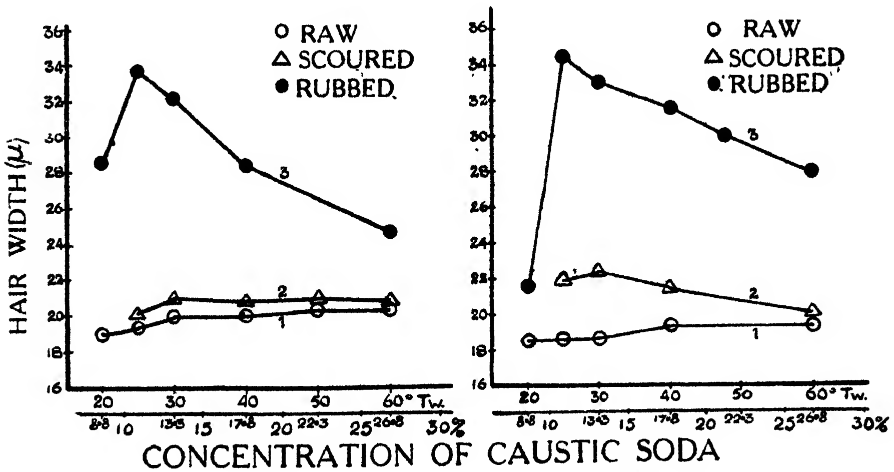

FIG 17
HAIR WIDTH, No. 226

FIG 18
HAIR WIDTH, No. 341

the raw cotton No. 226 on immersion of the hairs in single solutions of caustic soda, curve 2 shows the width of the scoured, and curve 3 the width of the rubbed hairs on immersion in the same solutions. The data obtained for cotton No. 341 are similarly plotted in Fig. 18. As has been previously pointed out,[8] the width of the raw collapsed hair cannot form an accurate standard from which to calculate per cent. changes in width, and for this reason in Figs. 17 and 18 the actual width in thousandths of a millimetre (μ) and not per cent. change is plotted vertically. The contour of a rubbed hair in caustic soda solutions, unlike that of a raw hair, is by no means regular, and measurements of width are of necessity inexact. Various sets of measurements have been made on the width of the rubbed hairs, however, and the

resulting curve has always been of the same form, exhibiting the marked maximum at 11·1%, and in all concentrations the great increase in width over that of the untreated and of the scoured hairs in the same concentration of caustic soda. Even if the curve for width values of the rubbed hairs is considered qualitatively rather than strictly quantitatively, there is still every indication from these data that in width change, as in shrinkage, the behaviour of the hair is influenced by mechanical treatment—apparently by the removal, to a greater or less degree, of some restriction to swelling.

III—EXPERIMENTAL

With the exception of those shown in Tables IV and V (Fig. 3), all observations on free shrinkage have been made by means of an apparatus that permits the measurement of the length of a hair in air or caustic soda solution under no load, its length under any given load, and the load necessary to produce any given extension of the hair. The experimental method makes use of a specially designed balance, and in this respect it follows the single-hair technique used by Willows, Barrett, and Parker,[7] but the gradual application of a load is achieved by means of a chain instead of the electromagnetic device used by those authors. The apparatus, illustrated in Fig. 19, is constructed from an Oertling "chainomatic" balance, with a chain that may

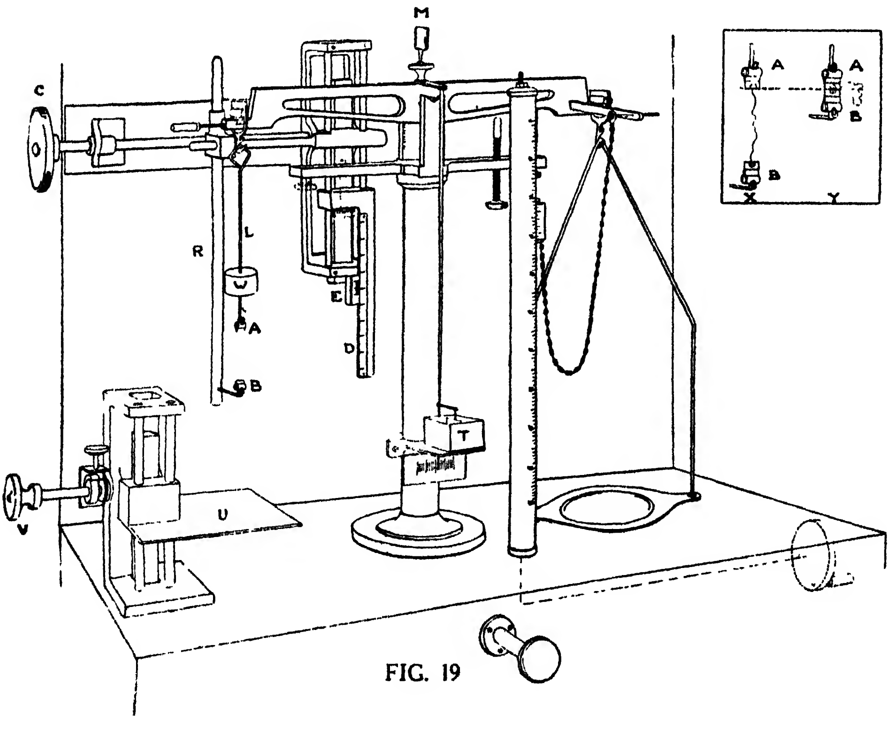

FIG. 19

be read accurately to 2 milligrams up to a load of 2 grams. The left-hand pan of the balance is removed and the right-hand pan is counterpoised by a nickel weight (W), attached to a light nickel rod (L), bearing at its end a small spring clip (A). Supported independently is a scale (D), graduated in millimetres, which moves vertically against a fixed vernier (E), and is connected

rigidly with a vertical rod (R), the movement being controlled by a fine rack and pinion operated by the disc (C); the scale may be accurately read to 0·1 millimetre. Attached to a projection from R, so as to be vertically below A, is another spring clip (B). The whole apparatus, except the operating discs, is enclosed in a glass case.

On the beam, at its mid point, is mounted a small plane mirror (M). About 3 feet from M, outside the balance case, an illuminated scale (S) is erected (Fig. 20), and by means of a second mirror and a telescope with cross

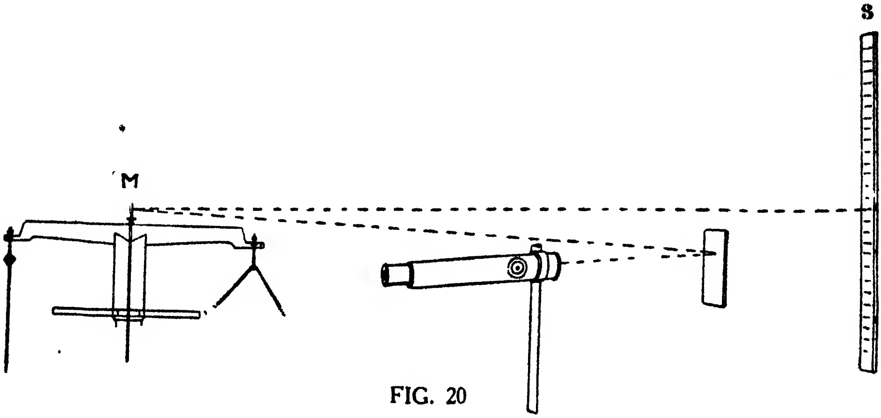

FIG. 20

wires, an observer seated at the balance may note any deflection in the beam of the balance by a change in the reading of the scale. The object of this arrangement (shown diagrammatically in Fig. 20) is to assist in adjusting the balance to its zero position as accurately as possible, and in detecting any displacement from that position.

All observations have been made at a temperature of approximately 18° C., but the temperature has not been accurately controlled. Each hair to be examined is mounted with an alcoholic solution of shellac between two pieces of thin copper foil about 8×5 millimetres in size. These are left overnight at a convenient temperature of 34° C., this being high enough to dry the shellac without injuring the hair. The shellac is then covered by paraffin wax of low melting point. Difficulty was at first experienced in finding a cement that would withstand the action of caustic soda, but this protection with paraffin wax has proved thoroughly efficient. The copper mounts carrying the hair are placed one in each of the grips A and B, as illustrated at X in the inset to Fig. 19. The beam is raised and the chain adjusted to bring the balance to its zero position. Oscillations of the beam are damped by a vane fixed on the pointer and moving in a bath of liquid paraffin (T). The rod R is raised by means of the rack and pinion operated from C until the two ends of the hair (where it emerges from its copper mounts) are in contact, or are in the same horizontal plane, as illustrated diagrammatically at Y in the inset to Fig. 19. The scale reading that corresponds to this position of the rod R defines the position of the upper end of the hair, and this remains unaltered throughout the observations on any one hair, since all readings are made with the beam in its zero position. The grip B is next lowered until the equilibrium of the balance is just upset as shown by a change in the reading of the scale S viewed through the telescope, and the reading on the scale DE is again taken. The difference

between this and the reading with the two ends of the hair in contact gives the "observed length of the hair" under no load, or, more strictly, under the very small load which is necessary to cause a detectable tremor in the mirror M. Some hairs are, however, not straightened under this small load (less than a milligram), and in order to overcome this difficulty the hair is observed under three or four loads applied by means of the chain in increments of 4 milligrams. When the hair is straightened, an increase in the load of this magnitude produces a change of length less than that which can be observed on the measuring scale (0·1 millimetre).

The load indicated by the chain is totally effective only when the beam is in the zero position; to apply a given load it is therefore necessary to adjust the chain to the position indicating that load, and then to lower the bottom grip B, and so depress the left-hand side of the balance, until the beam is again horizontal, as shown by a return to the zero reading on the scale S.

After measurement in air the hair is slackened by raising the grip B, and a vessel of caustic soda solution of the required concentration is brought up under the hair so as completely to immerse it, the grip A, and the rod L to a fixed mark below the weight W. The vessel is supported on a table U, which is raised and lowered by a rack and pinion operated from the disc V, outside the balance case. The immersion of the hair and grip in the liquid throws the beam out of its zero position, and it is brought back to this position by means of the chain; the scale reading corresponding to the upper end of the hair is then the same as it was in air. The hair is left slack in the solution for three minutes and subsequent examination has shown that deconvolution is practically complete under these conditions. The length of the hair in caustic soda solution is obtained by observations made under a series of small and progressively increasing loads, and in order to make this method clear a few detailed measurements will be recorded and discussed, on the behaviour of individual hairs of the scoured cotton No. 226, in air and in 22·3% caustic soda solution.

Fig. 21a records the lengths of six hairs in air under various small loads. The scale reading corresponding to the upper end of the hair remains constant irrespective of the load, owing to the fact that the beam is always adjusted to the horizontal (zero) position before an observation is made. The changes in the length of a hair produced by alterations of the load are, therefore, equal to the changes in the reading of the scale attached, through the rod R and the grip B, to the lower end of the hair, and these are plotted vertically in Fig. 21a for loads of 0, 4, 8, 12, and 16 milligrams. The *observed* reading under no load is that which corresponds to the first tremor of the beam mirror when the grip B is slowly separated from A, as shown by the magnifying system. In five of the hairs (1, 2, 3, 4, 6) the first 4 milligram load-increment produces a very small, but significant, change in the hair length, whilst subsequent equal increments produce no measurable change. In the sixth hair (5) the first 4 milligrams produces a relatively large change in length, but no further alteration occurs under subsequent load-increments. The large change under the first application of a load is probably due to the presence of some peculiar feature in the hair, such as a kink, that prevents it being easily straightened, and it is often found that when the whole operation is repeated the large change of length under the first application of a load is no longer observed; the attainment of a sensibly constant length under small load-increments checks the security of the grip. The use of

the "observed length" under no load would clearly lead to large errors with individual hairs, and the value adopted for the length in air under no load is, therefore, the constant value attained under small load-increments—usually, though not always, after the application of the first 4 milligrams.

Fig. 21b gives similar data for the same six hairs in 22·3% caustic soda. The hairs are more extensible in the alkali than in air, with the result that a sensibly constant length is not attained under small loads, but some of the load-length curves are characterised by initial irregularities similar to, and more pronounced than, those observed with hair No. 5 in air (Fig. 21a). The hairs numbered 1, 3, and 6, which showed no considerable discontinuities on loading in air, all show great initial irregularities on loading in caustic soda. When the hair shrinks freely in the alkali, rapid deconvolution occurs, and this is frequently accompanied by the formation of a loop that folds on itself. The behaviour of the hair is similar to that of a tightly twisted yarn

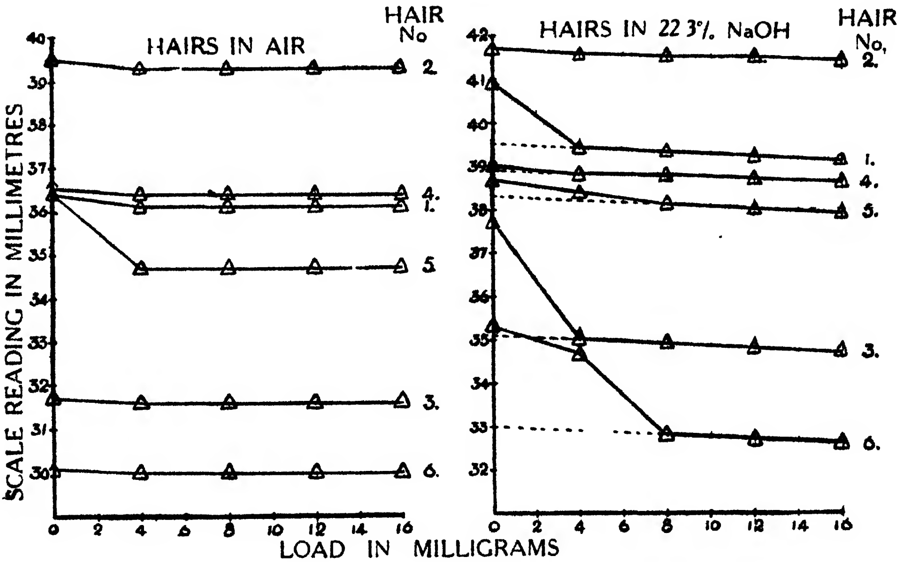

FIG. 21a FIG. 21b

loosely held, in which the untwisting tendency causes the formation of loops that fold on themselves—an effect known familiarly to the spinner as "snarling." When such loops are formed in the shrunk hair, a considerable tension is necessary in order to straighten it, and the initial irregularities observed in shrunk hairs (Fig. 21b) are frequently due to this cause, though other causes also operate. Here again, large errors would arise in individual observations if use were made of the "observed length" under no load. The value that is adopted as the basis of calculation is, therefore, the "calculated length" under no load, obtained by extrapolation from the smooth parts of the load-length curve, as shown by the broken lines in Fig. 21b.

Every hair dealt with in this apparatus (measurements of free shrinkage under no load, and under various loads subsequently applied slowly) has been submitted to the examination described above, though it is not generally necessary to plot the observations, simple inspection of the results enabling the extrapolated value to be obtained.

The technique whereby "restricted shrinkage" has been observed is extremely simple. The hair is mounted between a piece of copper foil, as used before, and a small piece of nickel wire of known weight. The copper foil is placed in a spring clip mounted at the end of a vertical rod, and the hair hangs freely under the known load of nickel wire. By means of a cathetometer, readings of the upper and lower ends of the hair are observed, and the difference between these is taken as the length of the hair, the extension in air under the loads used being negligible, provided the hair is straightened by the load. A small rectangular vessel of caustic soda solution is then brought up to immerse the hair, which is allowed to shrink against the known load for three minutes. The pieces of nickel wire are cut to a constant weight in air, and, with one exception, the variation in effective load caused by immersing the same mass in solutions of different densities has been neglected. This exception is in the restricted shrinkage of scoured hairs under 50 mg. load. These appear to be the conditions under which Willows, Barratt, and Parker[7] observed shrinkage, and it was in the hope of obtaining a curve similar to the one obtained by these authors that a load of exactly 50 mg. in each solution was used. This load was obtained by using a hook of nickel wire weighing 50 mg. in air, and before immersion, adding a rider appropriate to the solution and calculated from its density. The extremely slight gain in accuracy that results from the adoption of this method seems hardly to justify the further complication of an already sufficiently laborious technique, and with all other loads the method was abandoned. The exact loads applied in each solution are given in Table XV. It should be borne in mind that these slight inaccuracies apply only to data on "restricted shrinkage" and on "free shrinkage, rapid loading," and not to the general mass of data on free shrinkage. The effect of the shellac and wax has been neglected, but the amount used was reduced to a minimum. A load of 3 mg. does not always straighten a hair in air, therefore in measurements of shrinkage under 3 mg., a load of 5 mg. has been added while the hair is in air (8 mg. being sufficient to straighten all hairs examined) and removed before immersion in caustic soda solution.

In Tables IV and V (see also Fig. 3), values are given for free shrinkage measured under various loads, the loads being applied "rapidly," not gradually. These results have been obtained by employing a technique similar to that just described for restricted shrinkage, except that, before immersion of the hair in caustic soda solution, the load was supported on a metal plate, the hair being allowed to shrink freely without the constraint of the load. After 3 mins. the load was suddenly brought into operation by removal of the plate, and cathetometer readings were taken at once. After this measurement of length was made, hairs were often left loaded in the solution for 3 mins., but no measurable increase in length was ever observed.

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Shrinkage per cent. of Cotton Hairs in Sodium Hydroxide Solutions

Table No.	Cotton Sample No.	Method of Shrinkage Measurement	Pre-Treatment of Cotton	Load Mgms.	Concentration of Sodium Hydroxide: 8·8 g. per 100 g. (20° Tw.)		11·1 g. per 100 g. (25° Tw.)		13·3 g. per 100 g. (30° Tw.)		15·5 g. per 100 g (35° Tw)		17·8 g. per 100 g. (40° Tw.)		20·1 g. per 100 g. (45° Tw.)		23·3 g. per 100 g. (50° Tw.)		26·8 g. per 100 g. (60° Tw.)	
					Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ
I	226	Free shrinkage measured under various loads; slow loading	Raw	0	—	—	8·2	3·2	10·7	2·5	—	—	11·4	2·1	10·8	2·1	9·2	2·0	8·3	1·8
				8	—	—	7·5	3·0	9·8	2·0	—	—	10·5	2·1	9·9	2·0	8·5	2·0	7·8	1·7
				20	—	—	6·4	2·6	8·8	1·9	—	—	9·2	1·9	8·6	1·5	7·5	2·0	7·0	1·9
				42	—	—	5·4	2·5	7·6	1·8	—	—	7·9	1·6	7·4	1·4	6·6	1·8	6·4	1·9
				100	—	—	3·4	2·0	5·3	1·8	—	—	5·4	1·8	4·9	1·4	4·7	1·9	5·0	1·9
				130	—	—	2·4	2·1	4·3	1·7	—	—	4·3	1·7	3·8	1·4	3·8	2·0	4·2	2·0
				500	—	—	−2·3	2·2	−0·7	2·2	—	—	−1·4	1·9	−1·6	1·6	−1·0	2·4	−0·2	2·5
II			Scoured	0	—	—	9·5	3·4	16·9	2·9	—	—	14·6	2·5	13·3	1·9	12·4	2·2	8·7	1·7
				8	—	—	5·6	1·8	13·4	2·5	—	—	11·6	2·4	10·1	1·5	10·1	2·2	7·8	1·3
				20	—	—	4·9	1·7	12·5	2·3	—	—	10·4	2·5	9·3	1·7	9·0	1·8	7·3	1·4
				42	—	—	3·8	1·6	10·1	2·0	—	—	8·8	2·1	8·0	1·7	7·7	1·6	6·7	1·3
				100	—	—	1·8	1·6	7·3	1·8	—	—	6·1	2·1	5·6	1·6	5·7	1·4	5·1	1·4
				130	—	—	0·9	1·6	5·5	2·0	—	—	5·0	2·0	4·7	1·5	4·7	1·4	4·3	1·4
				500	—	—	−3·4	1·7	0·1	2·1	—	—	−0·5	2·2	−0·8	1·7	−0·4	1·4	−0·3	2·0
III			Raw, rubbed	0	3·9	3·1	18·4	3·4	18·1	2·2	—	—	16·4	3·8	—	—	—	—	9·6	1·9
IV		Free shrinkage measured under various loads; rapid loading	Scoured	8·6	—	—	6·7	1·8	14·5	2·8	—	—	12·4	3·2	10·8	2·5	10·3	2·1	7·5	1·3
				42	—	—	3·9	1·8	9·1	2·4	—	—	8·9	1·9	8·1	2·4	8·2	1·7	6·1	1·9
				130	—	—	0·5	2·0	5·2	2·3	—	—	6·2	1·4	4·8	1·5	4·5	1·5	3·9	1·8
V			Scoured by boiling for 6 hours with—																	
			(*a*) Water under atmos. pressure	8·6	—	—	—	—	14·9	3·3	—	—	—	—	—	—	—	—	—	—
			(*b*) 1% Na_2CO_3 atmos. pressure	8·6	—	—	—	—	13·6	2·7	—	—	—	—	—	—	—	—	—	—
			(*c*) 1% NaOH under 20 lb. excess pressure	8·6	—	—	—	—	14·4	2·8	—	—	—	—	—	—	—	—	—	—
VI		Restricted shrinkage under various loads	Raw	8·6	—	—	5·4	2·2	6·8	2·4	—	—	8·2	1·1	—	—	7·7	1·9	6·0	2·2
VII			Scoured	3	—	—	—	—	9·7	2·2	—	—	10·6	2·1	10·0	1·8	9·8	2·3	6·9	2·1
				8·6	—	—	2·4	1·6	7·6	1·9	—	—	8·4	1·8	8·3	1·8	7·3	2·4	5·8	1·8
				50	—	—	−1·2	1·7	1·7	1·7	—	—	1·8	1·6	1·9	1·6	2·2	1·7	2·6	1·2
VIII			Raw, solvent extracted	8·6	—	—	5·3	2·2	6·9	2·0	—	—	7·2	1·6	—	—	7·1	1·7	6·9	1·6
IX			Raw, rubbed	8·6	—	—	10·6	2·5	15·4	3·7	12·9	2·2	12·0	2·1	12·0	1·6	10·4	1·7	7·5	1·6
				17	—	—	8·4	2·3	10·8	2·5	9·8	2·0	9·9	2·3	9·5	2·0	9·3	1·6	6·1	1·6
				42	—	—	1·5	1·9	4·2	2·5	—	—	4·3	2·3	3·9	2·1	4·3	1·6	4·4	1·6
X	341	Free shrinkage slow loading	Raw	0	—	—	6·7	2·1	11·0	2·6	—	—	10·7	2·0	10·8	2·2	10·4	2·0	8·9	1·7
XI			Scoured	0	—	—	8·5	2·7	14·5	2·6	—	—	13·7	2·5	12·1	2·3	11·6	2·1	8·6	2·3
XII		Restricted shrinkage	Scoured	3	—	—	—	—	11·4	3·8	—	—	11·6	3·0	11·3	2·6	10·4	2·2	6·7	1·7

σ = Standard Deviation

Mean Hair Width (μ) of Cotton Hairs in Sodium Hydroxide Solutions

Table No.	Cotton Sample No.	Pre-Treatment of Cotton	Concentration of Sodium Hydroxide: 8·8 g. per 100 g. (20° Tw.)		11·1 g. per 100 g. (25° Tw.)		13·3 g. per 100 g. (30° Tw.)		17·8 g. per 100 g. (40° Tw.)		21·5 g. per 100 g. (48° Tw.)		22·3 g. per 100 g. (50° Tw.)		26·8 g. per 100 g. (60° Tw.)	
			Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ
XIII	226	Raw... ...	19·0	3·9	19·3	3·7	20·0	3·0	20·0	3·7	—	—	20·4	3·1	20·4	3·3
		Scoured ...	—	—	20·1	3·9	21·0	3·7	20·8	4·1	—	—	21·0	4·1	20·8	3·5
		Raw, rubbed ...	28·5	4·8	33·7	5·1	32·1	4·3	28·3	4·9	—	—	—	—	24·6	4·4
XIV	341	Raw... ...	18·5	2·7	18·5	3·4	18·6	2·8	19·3	2·5	—	—	19·3	2·6	19·4	3·2
		Scoured ...	—	—	21·9	4·7	22·4	4·7	21·3	3·8	—	—	—	—	20·0	3·2
		Raw, rubbed ...	21·6	3·5	34·4	6·0	33·0	3·8	31·5	4·2	29·3	4·7	—	—	27·8	3·8

σ = Standard Deviation

Table XV

Actual Loads applied to Hairs in Caustic Soda Solutions of Different Concentrations. Applicable to Data in Tables IV to X and XII

Nominal Load, Mgms.	Actual Load, Mgms. (weight in caustic soda solutions of following concentrations): 11·1 g. per 100 g.	13·3 g. per 100 g.	17·8 g. per 100 g.	20·1 g. per 100 g.	22·3 g. per 100 g.	26·8 g. per 100 g.
8·6	8·7	8·7	8·6	8·6	8·6	8·5
17	17·4	17·4	17·3	17·2	17·2	17·1
42	42·7	42·4	42·1	41·9	41·8	41·3
130	130·8	130·4	129·6	129·1	128·7	127·9

Table XVI

Concentration and Densities of Caustic Soda Solutions

Density	1·1	1·125	1·15	1·2	1·225	1·25	1·3
Density in ° Tw. ...	20	25	30	40	45	50	60
Grams NaOH per 100 g. of solution	8·8	11·1	13·3	17·8	20·1	22·3	26·8
Normality ...	2·4	3·1	3·8	5·3	6·2	7·0	8·7

22—THE SWELLING OF COTTON HAIRS IN WATER AND IN AIR AT VARIOUS RELATIVE HUMIDITIES

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INTRODUCTION AND SUMMARY

The swelling that accompanies the absorption of water by cotton does not appear to have formed the subject of any extensive measurements, in spite of its fundamental importance, though Haller[3] records a 23% increase of diameter of bleached American hairs on passing from the dry state to a water medium. It might be anticipated that a close parallelism would exist between the extent of the dimensional changes and the amount of the absorption, and the measurements recorded in this paper indicate that this is so, at all events between the temperature limits 20°–100° C. No evidence of increased swelling at temperatures up to 200° C. has been obtained.

SWELLING AT 20° C.

Experimental Method

Cotton hairs about 10 mm. long were mounted in plane-faced glass cells as described in an earlier paper,[1] and a microscope was used to determine the length changes and diameter changes of the hairs. The "diameters" obtained at any one humidity were the means of observations taken every 0·2 mm. along the length of the hair. Sea Island cotton (V 135) from one seed was treated loose with 15·2% sodium hydroxide solution, to smooth out the convolutions and other irregularities, washed, dried in the air, and kept at about 50% relative humidity. This formed the source of hairs for these experiments. In experiments 2, 5, 6, and 9, the cells were first filled with water in the lower portion or in a side bulb, and evacuated by a water pump. It was intended thus to observe the diameter and length in the saturated vapour, but actually water was generally condensed on the hair and owing probably to the fact that the hair was not hanging freely the figures for the length changes are low in these experiments for the initial 100% value. The water was then run out and an appropriate glycerol-water mixture introduced,[4] the cell re-evacuated and equilibrium awaited. The relative humidities used were 97%, 90%, 80%, 60%, 30%, and zero, dryness being attained by the use of phosphorus pentoxide. Rehydration was effected by the series, 30%, 60%, 80%, 90%, 97%, and water. In experiments 21–25, the procedure was modified as follows—The cell was initially filled with water so that the hair dimensions were obtained in that liquid. The water was then run out and air drawn through the cell till the liquid water was removed. The hair alone was now carefully wetted again and air of 97% R.H. passed through the cell. Except for the use of the air currents of various humidities the subsequent operations were similar to those above. The individual diameter readings were squared, and their means multiplied by an appropriate constant to give the mean areas. The area and length changes are given in Table I as percentages of the values at 0% relative humidity. Experiment 6 (which was not completed) and experiment 25 (which gave an abnormal value) being omitted, the mean values for seven experiments are obtained, and Fig. 1 represents these graphically, together with the regain curves for comparison (according to the data of Urquhart and Williams).[6]

Table I

Changes in Dimensions of Cotton Hairs at Different Humidities, relative to Dimensions at 0% R.H.

Relative Humidity %	Water (100)	97	90	80	60	30	0	30	60	80	90	97	Water
						Area changes; per cent.							
Expt. 2 ...	49·1	40·0	30·5	22·6	16·8	12·4	0	7·4	13·9	18·1	26·4	31·6	47·4
„ 5 ...	42·5	31·1	34·1	21·7	9·0	2·3	0	4·2	8·3	15·5	24·9	30·5	35·7
„ 9 ...	39·8	27·5	24·9	17·4	11·7	10·1	0	6·3	11·5	16·0	25·9	41·7	38·8
„ 21 ...	47·4	33·5	29·3	25·0	21·9	12·3	0	7·2	11·2	19·2	25·1	30·7	43·1
„ 22 ...	58·7	40·5	34·0	23·4	13·4	5·6	0	6·3	15·6	19·8	26·3	26·7	53·2
„ 23 ...	52·2	36·9	33·0	28·8	22·2	12·0	0	10·8	13·7	18·4	29·2	31·5	44·3
„ 24 ...	50·8	28·1	21·9	16·5	14·9	10·3	0	7·4	11·2	13·4	17·0	26·0	44·5
„ 6 ...	36·1	33·7	25·8	17·0	7·7	7·6	0	—	—	—	—	—	—
„ 25 ...	94·3	45·7	36·9	33·2	22·2	11·0	0	6·0	10·2	16·4	30·7	18·6	44·4
Mean of 7 ...	48·6	33·9	29·7	22·2	15·7	9·3	0	7·1	12·2	17·2	25·0	31·2	43·9
						Length changes; per cent.							
Expt. 2 ...	0·03	1·13	1·13	0·91	0·65	0·36	0	0·37	0·65	1·21	0·87	1·01	1·28
„ 5 ...	−0·71	0·91	0·91	0·77	0·65	−0·03	0	0·26	0·02	0·68	0·97	1·12	1·36
„ 9 ...	0·03	1·08	0·89	1·08	0·73	0·38	0	0·70	0·77	1·13	1·28	1·80	1·80
„ 21 ...	1·18	1·24	0·94	0·94	0·91	0·59	0	0·33	0·43	0·76	0·78	0·91	1·11
„ 22 ...	−0·62	−0·79	−0·84	−0·87	−1·12	−0·29	0	0·19	0·52	0·50	0·66	0·86	1·14
„ 23 ...	0·16	−0·07	−0·29	0·31	0·31	0·00	0	0·03	0·16	0·16	0·28	0·31	0·44
„ 24 ...	0·59	0·56	0·42	0·29	0·00	0·07	0	−0·29	−0·04	0·42	0·45	0·45	0·69
„ 6 ...	0·55	0·68	0·51	0·40	0·16	0·37	0	—	—	—	—	—	—
„ 25 ...	0·80	0·66	0·61	0·80	0·58	0·42	0	0·21	0·36	0·54	—	0·69	—
Mean of 7 ...	0·09 ?	0·58	0·46	0·49	0·30	0·15	0	0·23	0·36	0·69	0·76	0·92	1.12

A more critical comparison may be made by obtaining the ratio of observed swelling to that calculated on the assumption of increase in volume solely due to addition of water at normal specific volume. The specific volume of the cotton being assumed to be 0·647 (cf. Davidson[2]), the water volume added per unit volume of dry cotton $= \alpha/0{\cdot}647$, where α is the regain, and the ratio required is $\Delta v \times 0{\cdot}647/\alpha$. Each experimental point being calculated for an observed Δv, the corresponding value is obtained for this ratio, which is evidently the apparent specific volume of the water. The means are—

	Water	97	90	80	60	30
Desorption...	0·956	0·836	0·946	0·840	0·971	0·987
Absorption	0·878	0·860	0·843	0·965	0·880	0·890

Now the mean of seven quantities may vary over a range $4\,\sigma/\sqrt{7}$ approximately,* where σ is the standard deviation. The values for this range are given below—

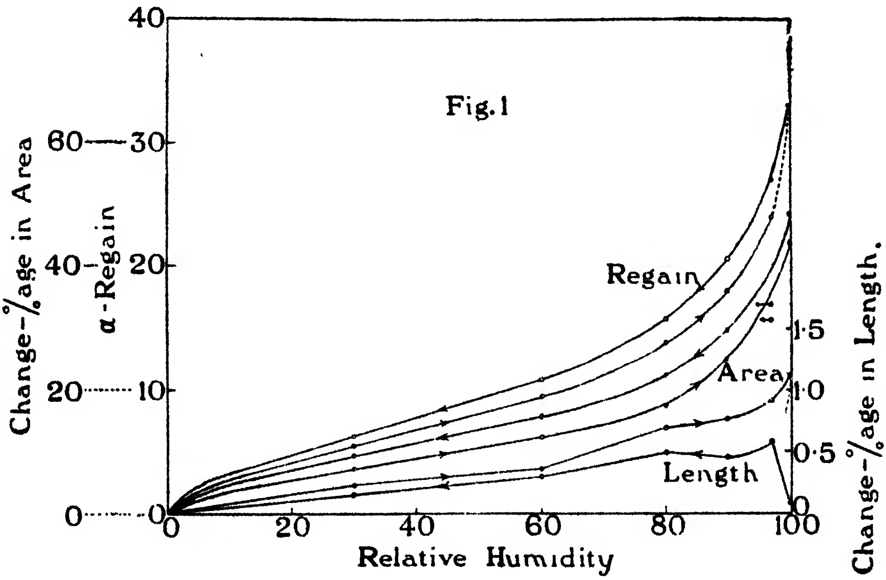
R.H. ...	Water	97	90	80	60	30
$4\,\sigma/\sqrt{7}$ ...	0·183	0·157	0·190	0·260	0·470	0·645
R.H. ...	30	60	80	90	97	Water
$4\,\sigma/\sqrt{7}$ ...	0·296	0·267	0·165	0·219	0·240	0·157

Thus for example—

In water (absorption) the mean may be between 0·799 and 0·956.

Or at 30 R.H. (absorption) ,, ,, ,, 0·742 and 1·038.

From this it is clear that the figures are not capable of yielding any quantitative information as to the variation or significance of the value of the apparent specific volume of the absorbed water.



Inspection of the desorption and absorption figures might lead to the conclusion that the specific volume of the water is less in absorption than in

*The approximate nature of the criteria applied must be emphasised and no exact significance attached to the apparent high accuracy of calculations which are based on arbitrary limits. For details of calculations of the quantities "t," "p," etc., see Fisher's "*Statistical Methods for Research Workers.*"

desorption, but statistical examination shows that the difference though suggestive is not proved real, for if the figures are compared by determining each difference separately and finding the mean of these 42 quantities and its standard error, it is found that the mean difference = 0·0509, the standard error = 0·0326, and the ratio = t = 1·56, for which p = 0·12 approximately; that is, the chances that the difference is significant are 8:1 in favour, which is inadequate.

In Fig. 1 the absorption length change isotherm lies above the desorption curve. This is not to be expected, and here also the significance of the difference between absorption and desorption values was examined. Excluding water values, 35 pairs of observations give—Mean difference between absorption length and desorption length = +0·20%; standard error = 0·098; t = 2·01; p = 0·051, which is about the usually accepted level of significance (0·05). The significance of this difference therefore remains undecided. If the area changes are similarly examined there is no doubt as to the significance of the swelling hysteresis indicated by the graph, for 42 pairs of observations give mean difference = 3·83, *S.E.* = 0·67, t = 5·76, and $p < 0.01$.

The conclusion is therefore drawn from these experiments that the swelling of cotton hairs as deduced from "diameter" measurements manifest a hysteresis similar to the regain curve, but that the significance of any difference between the length change curves is undecided.

VARIATION OF SWELLING IN WATER WITH TEMPERATURE

Hairs were mounted in short cells of plane-faced glass tubing and the cells filled with boiled distilled water, evacuated and sealed off. The cells were then held in a miniature bath containing B.P. paraffin, the temperature of which could be controlled by electric heating, mounted on the stage of a projection microscope, and the diameters of the hairs determined. In experiments 1–7 mercerised V 135 Sea Island hairs were used, and in experiments 9–12 soda-boiled 85 R American Upland. The diameter changes given in Table II are small, and of the order to be expected if relationship to the variation of water absorption is postulated.

Table II

Temperature	20° C.	40° C.	60° C.	80° C.	100° C.	120° C.
Expt. 1	1·000	0·987	1·017	1·032	0·989	—
„ 2	1·000	—	0·985	1·002	1·021	—
„ 3	1·000	0·990	0·950	0·978	0·978	0·970
„ 4	1·000	1·041 ?	0·992	0·995	1·020	1·010
„ 5	1·000	0·991	1·000	0·960	0·931	0·961
„ 6	1·000	0·981	0·984	0·986	0·967	0·954
„ 7	1·000	0·976	0·960	0·976	0·981	0·990
„ 9	1·000	0·989	0·959	0·959	1·04	1·01
„ 11	1·000	0·990	0·978	0·990	1·014	1·034
„ 12	1·000	0·978	0·980	1·008	1·000	1·017
Means	1·000	0·985*	0·981	0·989	0·994	0·993
Areas	1·000	0·970	0·962	0·978	0·988	0·986

*Omitting doubtful value (Expt. 4).

Fig. 2 shows graphically that the swelling of these hairs and the regain of soda-boiled 85 R cotton (as obtained by extrapolation of Urquhart's data)[5] and the variation of swelling with temperature calculated from specific

volume figures by Davidson[2] run similar curves against temperature. The length changes which were observed were in general so small (about 0·5%) and irregular that they are not here reproduced.

In one experiment the hair was taken to 200° C., but the swelling observed was less than 5 per cent. In this connection it may be of interest to observe that experiments have also been made upon pieces of cotton fabric in water, in an autoclave at temperatures up to 220° C. under loads equivalent to 0·13 gm. per hair, but no evidence of any plasticity usually associated with pronounced swelling could be detected.

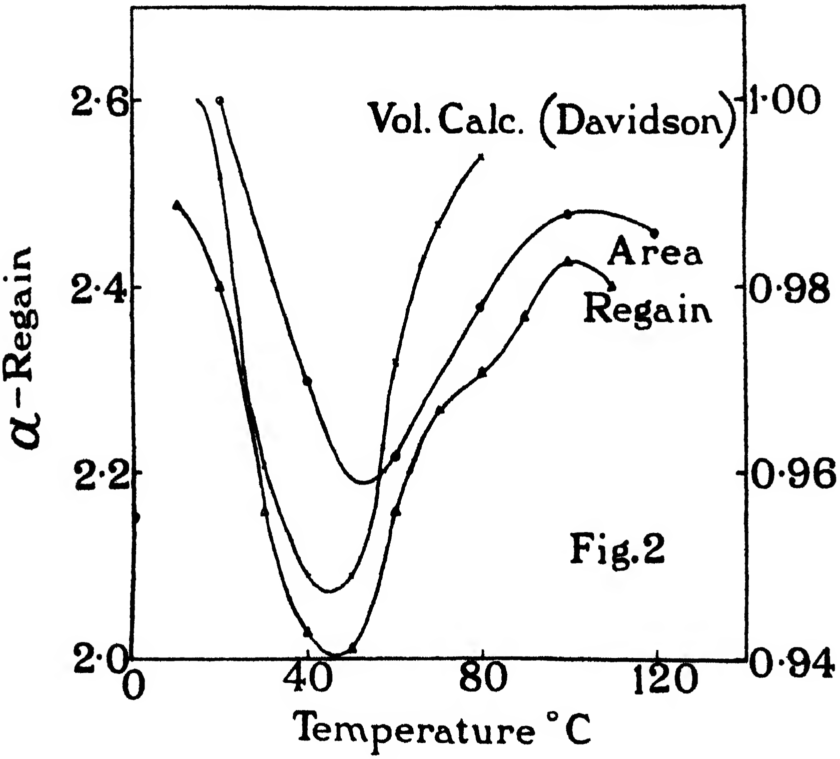


Fig. 2

Mr. L. H. C. Tippett, of this Institute, has assisted with the statistical part of this work. Most of the observations have been made by Mr. F. G. Wilde and Mr. W. Bostock.

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23—THE EXTENSIBILITY OF COTTON HAIRS

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INTRODUCTION AND SUMMARY

Observations have been made on the extension and recovery of single hairs from a sample of cotton that had been soaked in caustic soda solution to smooth out the convolutions. All the hairs were subjected to the same load, and measurements were made of the mean diameter and length, initially, after loading, and after removal of the load. The observations were conducted at a series of humidities ranging from zero to 100%, and twenty-five hairs were tested at each humidity.

The outstanding results are as follows—

(1) The correlation between the extension (or recovery) and the diameter of the hairs is quite different from what one would expect from a series of hairs of the same material. On a casual inspection, the results seem to indicate that on the whole the extension (or recovery) of the thinner hairs does not differ appreciably from that of the thicker hairs, but statistical analysis shows that there is at low humidities a negative correlation between extension and the reciprocal of the area of cross section of the hair, indicating that on the whole the fine hairs extend rather less than the coarse hairs.

(2) There is a very good correlation between the percentage extension imposed at a given humidity, and the subsequent recovery (or the residual extension). Thus, at 80% relative humidity an extension of 6% whether of a thick or a thin hair is followed by a recovery of about 2·1 per cent.

(3) The extensibility increases very much with increase in humidity, being about eight to ten times as great at saturation as at zero humidity.

(4) The hair makes a more complete recovery from a given extension at the higher humidity.

(5) The absolute values obtained for the Young's Modulus of the hairs range from 6×10^{10} dynes/cm.^{2} at zero humidity to $0{\cdot}6 \times 10^{10}$ dynes/cm.^{2} in water.

EXPERIMENTAL DETAILS

Method of Testing

The material used was Sea Island (V135) cotton, treated loose with 15·2% caustic soda, washed, and dried. In each experiment a single hair was mounted under a tautening load of 10 mg. in the plane-faced glass cell previously described,[1] the lower part of which was filled with phosphorus pentoxide when working at zero humidity or with one of a series of glycerol solutions covering the following range of humidities[4]—

R.H. at 20° C. ...	97	90	80	60	30
Glycerol % ...	16·7	35·0	52·7	73·4	95·0

The apparatus was kept overnight approximately at 20° C. and tested in a room at very nearly the same temperature. Observations were made of length and diameter, (1) under the tautening load, (2) after subjection to a load of 400 mg. for an hour, (3) one hour after release of the load, leaving again only the tautening load. To measure the diameter, readings were taken with a micrometer microscope every 0·2 mm. along the length of the hair, giving about 50 readings, and averaged. Twenty-five hairs were tested at each of the humidities given above, at zero humidity and also in water. Another group of 50 hairs was also tested at zero humidity.

Results

The more immediate data of the experiments are given in Table I. The values in any row of the table relate to the 25 hairs measured at the humidity indicated on the left of the figures. The first line of figures for each humidity labelled Area (1), is the mean area of cross section of the hair before loading, obtained by averaging the squares of the approximately 50 arbitrary values of the measured diameter and multiplying the average by $M^2\pi/4$, where M is the microscope magnification constant. Area (2) and Area (3) are the corresponding values after loading and after recovery respectively. These values are subject to a certain error due to the rather irregular shape of the cross section of the hair. This error is, of course, much less with mercerised than unmercerised hairs, but in any case the values of "area" are a measure of the visual coarseness or fineness of the hairs.

The fourth line of figures gives the percentage extension produced by the load of 400 mg. expressed as a percentage of the original length, which in all cases was about 10 mm. The fifth line gives the recovery on removal of the load expressed in the same manner. The sixth line gives the residual extension, which is the difference between imposed extension and recovery.

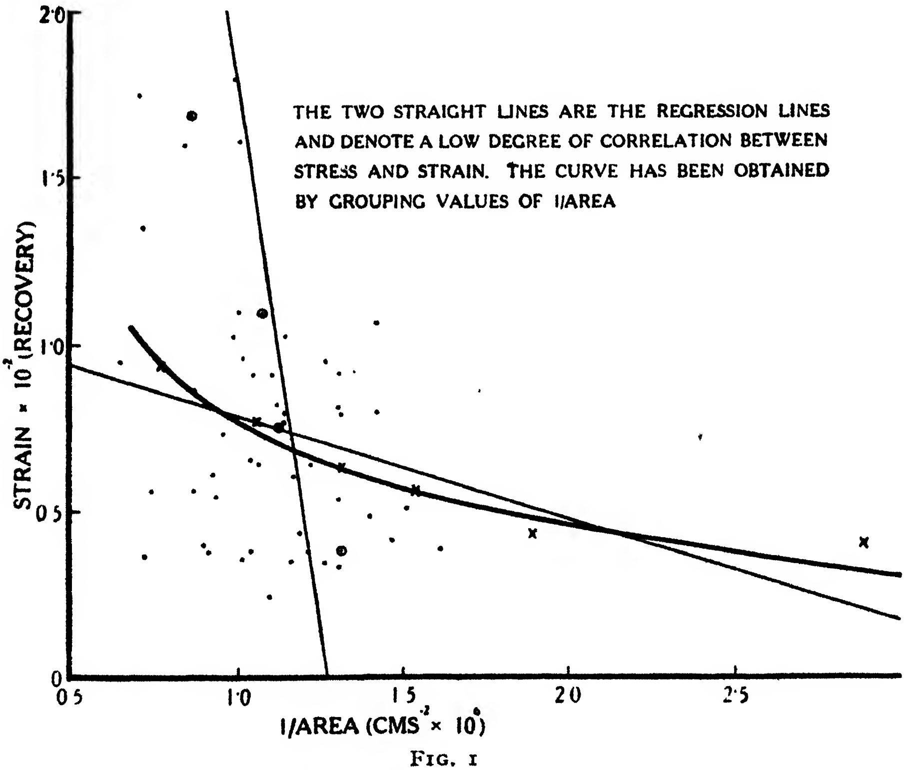

FIG. 1

The correlation between hair thickness and extension—In Fig. 1 are plotted the values of the percentage extension of each hair against corresponding values of the reciprocal of the area of cross section. These values are for 50 hairs tested at zero humidity. Similar diagrams are given by the results at other humidities, though, of course, the actual extensions are on the whole the greater the higher the humidity. The extensions vary enormously at any one humidity, but do not appear to be related in any simple manner to

Table I

0% R.H.	Area 1 ...	0·993	0·687	1·190	0·667	0·973	0·789	0·879	1·304	0·667	1·285	0·949	0·906	0·753	1·239	0·631	1·010	0·654	0·687	0·771	0·760	0·833	1·085	0·953	0·884	1·239
	Area 2 ...	1·085	0·664	1·262	0·718	1·010	0·837	0·899	1·269	0·650	1·039	0·870	0·925	0·659	1·121	0·728	0·928	0·598	0·782	0·764	0·705	0·720	1·072	0·929	0·871	1·159
	Area 3 ...	0·937	0·681	1·190	0·690	0·918	0·761	0·922	1·272	0·634	1·150	0·898	0·949	0·852	1·239	0·692	0·970	0·661	0·749	0·714	0·694	0·981	1·081	0·929	0·818	1·172
	% Extension	2·39	2·01	1·88	1·62	1·61	1·40	1·38	1·36	1·27	1·25	1·24	0·97	0·95	0·91	0·87	0·80	0·75	0·73	0·72	0·68	0·56	0·41	0·33	0·33	0·22
	% Rec. Ext.	1·90	1·48	1·88	1·76	1·11	1·29	1·28	1·04	1·26	0·78	0·76	0·85	0·45	0·79	0·69	0·80	0·69	0·53	0·58	0·43	0·46	0·37	0·33	0·21	0·22
	% Res. Ext.	0·49	0·53	0·00	−0·14	0·50	0·11	0·10	0·32	1·01	0·47	0·48	0·12	0·50	0·12	0·19	0·00	0·06	0·20	0·14	0·25	0·10	0·04	0·00	0·12	0·00
30% R.H.	Area 1 ...	0·786	0·664	1·450	0·787	0·705	0·945	1·131	0·672	0·945	0·745	1·145	1·014	0·740	0·565	1·216	0·593	0·659	0·754	0·628	0·826	0·782	0·872	0·864	0·837	1·217
	Area 2 ...	0·757	0·758	1·434	0·853	0·754	0·954	1·100	0·586	0·930	0·772	1·127	1·109	0·754	0·574	1·258	0·595	0·673	0·769	0·592	0·783	0·796	0·917	0·910	0·810	1·049
	Area 3 ...	0·769	0·726	1·498	0·821	0·721	0·910	1·276	0·692	0·812	0·722	1·217	1·061	0·749	0·573	1·268	0·603	0·675	0·819	0·655	0·702	0·852	0·958	0·935	0·775	1·149
	% Extension	4·46	4·00	3·79	2·52	2·34	2·16	1·69	1·49	1·37	1·31	1·26	1·13	1·12	1·12	1·09	0·89	0·78	0·75	0·74	0·69	0·76	0·67	0·66	0·60	0·59
	% Rec. Ext.	1·99	1·92	1·17	1·22	1·59	1·23	1·09	0·98	1·13	0·76	0·40	0·99	0·75	0·58	0·89	0·69	0·56	0·22	0·38	0·56	0·59	0·45	0·41	0·38	0·53
	% Res. Ext.	2·47	2·08	2·62	1·30	0·75	0·93	0·60	0·51	0·24	0·55	0·86	0·14	0·37	0·54	0·20	0·20	0·12	0·53	0·36	0·13	0·17	0·22	0·25	0·22	0·06
60% R.H.	Area 1 ...	0·993	0·702	1·211	1·789	0·911	1·130	1·013	1·238	1·012	1·039	1·053	0·873	1·162	1·140	1·121	0·968	1·711	1·277	1·147	1·078	1·233	0·903	0·918	1·403	0·827
	Area 2 ...	1·059	0·694	1·050	1·562	0·895	1·030	0·906	1·130	1·050	1·172	1·212	0·773	1·156	1·071	1·189	0·944	1·670	1·130	1·114	1·070	1·202	0·959	0·911	1·329	0·901
	Area 3 ...	1·120	0·680	1·083	1·863	0·917	1·109	0·928	1·210	1·049	1·163	1·171	0·878	1·118	1·164	1·190	0·877	1·613	1·293	1·161	1·149	1·215	0·916	0·926	1·382	0·785
	% Extension	5·92	5·09	4·49	3·24	3·20	2·51	2·41	2·27	1·85	1·79	1·70	1·59	1·48	1·48	1·41	1·36	1·29	1·22	1·12	1·05	1·00	0·96	0·81	0·65	0·57
	% Rec. Ext.	1·42	1·06	2·92	1·85	1·09	1·28	1·55	1·29	1·39	1·25	1·07	0·75	0·98	0·68	0·99	0·75	0·48	1·16	0·69	0·93	0·60	0·69	0·59	0·38	0·46
	% Res. Ext.	4·50	4·03	1·57	1·39	2·11	1·23	0·86	0·98	0·46	0·54	0·63	0·84	0·50	0·80	0·42	0·61	0·81	0·05	0·43	0·12	0·40	0·27	0·22	0·27	0·11
80% R.H.	Area 1 ...	0·687	1·369	1·470	1·436	1·115	1·301	1·658	1·155	1·422	1·099	1·624	0·950	1·589	1·738	0·905	0·878	1·119	0·952	0·770	1·187	1·094	0·951	0·894	1·123	1·730
	Area 2 ...	0·670	1·303	1·391	1·490	1·030	1·431	1·706	1·198	1·293	1·008	1·730	0·879	1·547	1·821	0·911	0·938	1·027	0·945	0·734	1·129	1·038	0·938	0·995	1·250	1·614
	Area 3 ...	0·685	1·278	1·411	1·417	1·140	1·431	1·650	1·072	1·211	1·067	1·590	0·935	1·460	1·747	0·916	0·877	1·064	0·917	0·746	1·131	1·067	0·966	1·011	1·178	1·540
	% Extension	8·03	6·70	5·75	5·55	5·00	4·86	4·66	4·42	4·00	3·84	3·45	3·25	3·09	2·82	2·59	2·35	2·10	2·03	2·01	1·87	1·75	1·69	1·37	1·01	0·98
	% Rec. Ext.	1·69	2·01	2·18	2·50	1·90	1·60	1·95	2·34	2·28	1·96	1·42	2·27	1·52	1·18	1·40	1·90	1·09	1·34	1·67	1·57	0·87	1·42	0·63	0·83	0·55
	% Res. Ext.	6·34	4·69	3·57	3·05	3·10	3·26	2·75	2·08	1·72	1·88	2·03	0·98	1·57	1·64	1·19	0·45	1·01	0·69	0·34	0·30	0·88	0·27	0·74	0·18	0·43
90% R.H.	Area 1 ...	1·132	1·440	1·688	1·570	0·890	1·160	0·918	1·691	0·892	1·459	1·032	1·298	1·360	1·230	1·343	0·949	1·095	1·212	1·319	1·059	1·007	1·155	1·295	1·024	1·040
	Area 2 ...	1·131	1·690	1·790	1·300	0·885	1·132	0·845	1·630	0·870	1·327	1·090	1·353	1·318	1·327	1·402	1·083	1·058	1·191	1·263	1·041	0·946	1·121	1·222	1·015	1·100
	Area 3 ...	0·916	1·684	1·687	1·490	0·904	1·112	0·888	1·480	0·821	1·205	1·100	1·345	1·317	1·210	1·453	0·940	1·053	1·255	1·440	1·048	0·994	1·233	1·148	1·063	0·992
	% Extension	10·91	9·28	7·32	7·30	7·00	6·81	6·06	5·83	5·01	4·97	4·94	4·44	3·91	3·77	3·26	3·08	3·05	2·97	2·95	2·90	2·63	2·78	2·28	2·28	2·27
	% Rec. Ext.	3·60	2·41	2·12	2·85	3·15	3·20	2·54	2·16	2·81	2·24	2·22	2·04	3·32	1·77	2·51	1·97	2·23	2·14	2·24	2·52	1·58	1·89	1·87	1·19	1·91
	% Res. Ext.	7·31	6·87	5·20	4·45	3·85	3·61	3·52	3·67	2·20	2·73	2·72	2·40	0·59	2·00	0·75	1·11	0·82	0·83	0·71	0·38	1·05	0·89	0·41	1·09	0·36
97% R.H.	Area 1 ...	1·393	1·539	1·242	1·115	1·930	1·456	1·851	1·671	1·260	1·908	1·412	1·430	1·742	1·113	0·945	1·285	1·212	1·480	1·728	1·160	2·094	1·323	1·390	0·850	2·308
	Area 2 ...	1·399	1·625	1·164	1·058	1·810	1·312	1·678	1·603	1·172	1·720	1·363	1·440	1·571	1·053	0·968	1·114	1·107	1·628	1·907	1·209	1·751	1·195	1·351	0·910	2·176
	Area 3 ...	1·404	1·673	1·210	0·995	1·865	1·347	1·698	1·680	1·323	1·781	1·268	1·508	1·590	1·103	0·911	1·160	1·204	1·562	1·950	1·253	2·128	1·230	1·400	0·960	1·961
	% Extension	13·40	9·19	9·17	7·89	7·88	7·77	7·30	6·61	5·98	5·89	5·70	5·69	5·63	5·30	5·13	4·89	4·82	4·23	3·83	3·66	3·40	3·27	2·98	2·40	1·53
	% Rec. Ext.	3·35	2·85	3·30	3·07	3·07	2·95	3·21	2·78	3·17	2·59	2·56	3·01	3·15	3·45	2·56	2·20	2·07	2·54	1·95	2·16	2·24	1·60	1·76	1·37	1·41
	% Res. Ext.	10·05	6·34	5·87	4·82	4·81	4·82	4·09	3·83	2·81	3·30	3·14	2·68	2·48	1·85	2·57	2·69	2·75	1·69	1·88	1·50	1·16	1·67	1·22	1·03	0·12
In Water	Area 1 ...	1·716	1·140	1·694	1·758	1·180	1·520	1·620	1·424	1·520	1·410	2·165	1·421	1·408	1·503	1·032	1·670	1·112	1·310	1·264	1·629	1·356	1·635	1·700	1·385	1·407
	Area 2 ...	1·539	1·117	1·696	1·679	1·230	1·480	1·597	1·429	1·581	1·345	1·955	1·500	1·481	1·510	1·102	1·596	1·112	1·350	1·159	1·507	1·285	1·575	1·830	1·272	1·462
	Area 3 ...	1·628	1·334	1·731	1·620	1·279	1·490	1·621	1·370	1·540	1·350	2·115	1·480	1·483	1·545	1·182	1·589	1·076	1·268	1·261	1·500	1·354	1·562	1·789	1·412	1·479
	% Extension	10·75	9·82	7·78	7·61	6·76	6·64	6·48	6·36	5·80	5·69	5·65	5·48	5·23	5·10	4·87	4·36	3·92	3·77	3·66	3·54	3·22	3·14	3·01	2·70	2·58
	% Rec. Ext.	3·32	7·07	4·67	3·80	1·36	5·11	3·11	3·37	4·06	3·13	3·44	3·67	3·50	3·58	3·10	2·62	2·59	2·64	2·40	3·04	2·96	2·04	1·41	2·27	1·96
	% Res. Ext.	7·42	2·75	3·11	3·81	5·40	1·53	3·37	2·99	1·74	2·56	2·21	1·81	1·73	1·58	1·71	1·74	1·33	1·13	1·26	0·50	0·26	1·10	1·60	0·43	0·62

Rec. Ext. = Recovered Extension. Res. Ext. = Residual Extension.

the hair thickness. In this connection it may be pointed out that for a series of metal wires of the same material having no "skin effect" and not loaded beyond their elastic limit, the points would lie in a straight line passing through the origin.

In Fig. 1 the elastic portion of the extension has been plotted, i.e. the recovery on removal of the load. If the actual extension is plotted the resultant diagrams show a similar scatter.

So far as a visual inspection of the diagrams goes, there seems to be no correlation between the extension (either total or recoverable) and the thickness of the hairs, except possibly at low humidities. The results of a statistical analysis of the results is shown in Table II, in which the coefficient of correlation (r) between the elastic portion of the extension and the reciprocal of the area is shown for each humidity. As a test of the significance of the coefficients the values are given of the probability (p) of such a value of the coefficient arising from random sampling. The conventional limit is $p < 0{\cdot}05$. From Table II the values $p = 0{\cdot}018$ (for 75 experiments at zero R.H.) and $p = 0{\cdot}01$ (125 experiments from 60 R.H. — 0 R.H.) indicate chances of 54:1 and 99:1 against the correlation being due to random errors.

Table II

Correlation of "Strain Recovered" (y) and 1/area (x)

Conditions	No. of Hairs	r	Mean r	p	Standard Deviations σx	σy
Water ...	25	0·010			0·11	1·20
97% R.H. ...	25	0·077	0·100	> 0·1	0·19	0·63
90% ,, ...	25	0·211			0·21	0·53
80% ,, ...	25	0·014		> 0·1	0·27	0·54
60% ,, ...	25	−0·260			0·23	0·54
30% ,, ...	25	−0·152	−0·253	0·01	0·32	0·47
0% ,, ...	25	−0·216	−0·282	0·018	0·27	0·51
0% ,, ...	50	−0·314			0·35	0·35

Fig. 1 also shows the regression lines and the "grouped means" curve, that is, the curve obtained from points calculated by grouping the results between limits of 1/area. If, as the curve suggests, the relationship is really better expressed by a curve than the straight line, then the significance and strength of the relationship is underestimated by the correlation coefficient.

Analogous to these results were those of Miss Clegg,[1] who showed that the finer kinds of cotton possess greater breaking stresses, but that the breaking load is independent of the diameter of the hairs.

If the total extension is similarly analysed, it is found that there is a significant correlation at zero humidity, and an insignificant correlation at higher humidities.

These results show that cotton hairs behave very differently from a collection of fine wires of uniform material and different diameters. That there should be some such difference is to be expected, since a cotton hair is a heterogeneous structure. The quantitative elucidation of this difference is obviously a matter for further research into the structure and internal dynamics of the hair, but two points may be mentioned at this stage.

In the first place the calculated area is not a perfectly sure guide to the amount of elastic material in the hair. What one measures is the "hair width," the mean square of which is taken as a measure of the area of the

cross section. Morton[3] has found a good correlation coefficient (0·95) between the square of the hair width and the hair weight per centimetre for hairs of widely different origins, but whether an equally good correlation would be found for the smaller variations within one variety is not certain.

In the second place it is possible that the thicker hairs may consist of more extensible material than the finer hairs. This might arise from the spiral structure of the hairs.

If two spiral springs are made of the same wire to different spiral diameters and the same angle of twist, the one with the larger diameter will be the more extensible (in proportion to the square of the diameter). If made to the same number of turns per unit length the discrepancy will be still greater.

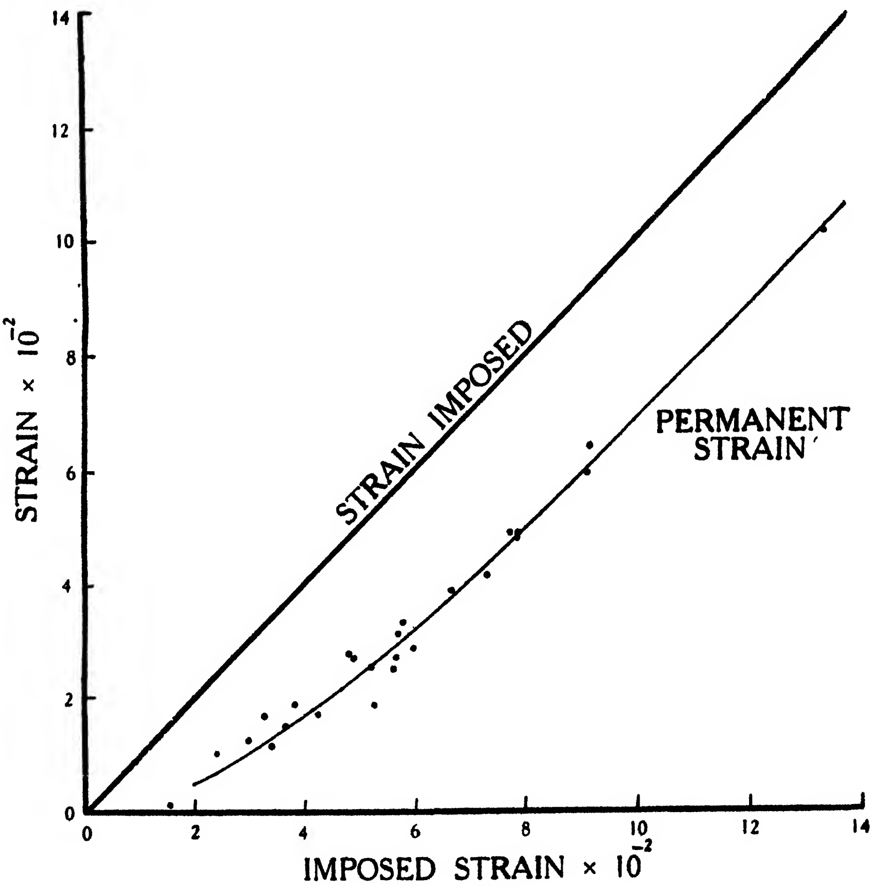

FIG. 2

The correlation between imposed extension and residual extension—When the data relating purely to the structure of the hair (i.e. the imposed and residual extensions and the elastic recovery) are considered apart from dynamical questions (i.e. the actual force resisting deformation), they show a high degree of regularity. There is very good correlation between the imposed extension and the residual extension (and, of course, the elastic recovery). This is illustrated in Fig. 2 where the data for 97% relative

humidity have been plotted. The values of the imposed extension (5th line of the 97% portion of Table I) have been plotted as abscissæ against the residual extension (7th line) as ordinates, and a smooth curve has been drawn through the points. The amount of elastic recovery is indicated by the vertical distance between the line drawn at 45° with the axes and any point (or the curve). Similar results are given by the data for the other humidities. If the imposed extension (%) is denoted by x and the residual extension by y, the results at any humidity may be fitted by a curve of the type—

$$y = A + Bx + Cx^2$$

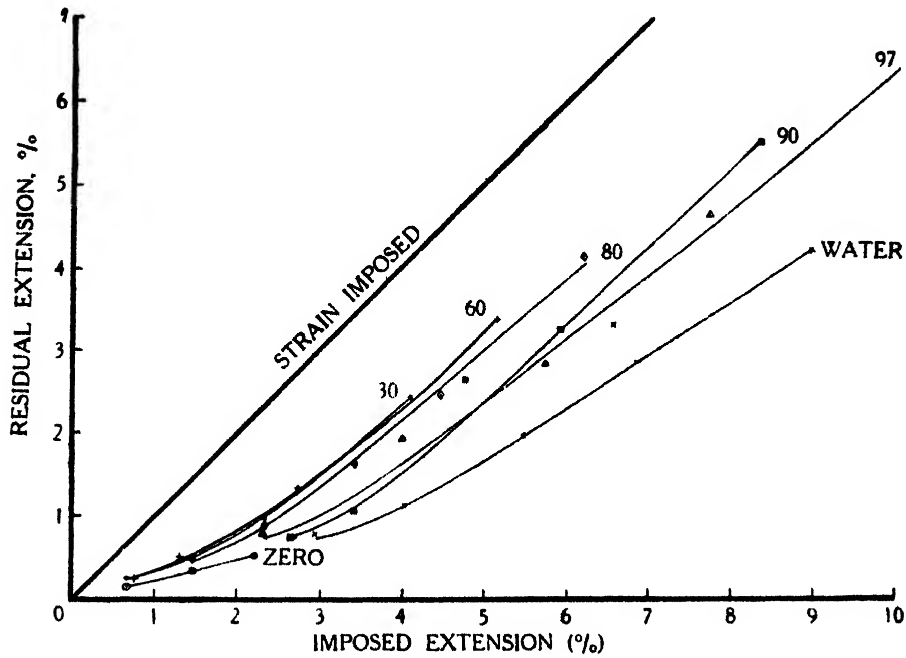

FIG. 3

The values of the constants A, B, and C at the different humidities are as follows—

	A	B	C
0%*	+0·03	+0·193	+0·0371
30%	−0·02	+0·274	+0·0741
60%	+0·17	+0·067	+0·1114
80%	−0·05	+0·244	+0·0686
90%	−1·38	+0·754	+0·0074
97%	−0·57	+0·495	+0·0228
100% (in water)	−0·21	+0·227	+0·0332

*The constants for zero humidity have been calculated from the data for 75 hairs, the 25 of Table I and an additional 50.

The curves through the "grouped means" points for the different humidities (25 experiments each) are shown in Fig. 3. It will be seen that for a given imposed extension the hairs extended in the highest humidities have the least residual extension, i.e. make the best recovery.

The recovery at zero humidity is apparently greater than at 30 R.H., but owing to the large scatter of the zero R.H. values this cannot be proved with any high degree of probability.

It was found that a curve similar to Fig. 2 can be obtained by examining the length changes of an aluminium helical spring of suitable dimensions.

Extension and Humidity—In spite of the large "scatter" of the values of the extension at any given humidity, there is a very close correlation between the mean extension and the humidity. In Table III are given the mean values of the imposed extension, recovery, and residual extension, together with the ratio of the residual extension to the imposed extension. Since the validity of the comparison of the mean results at different humidities depends essentially on whether each sample of 25 hairs represents with sufficient accuracy the bulk of the cotton, the "probable error" of each mean is placed in brackets after it. The "probable errors" marked with an asterisk are of doubtful value since the data to which they refer give a skew distribution.

Table III

R.H.	Imposed Extension %	Recovery %	Residual Extension %	Residual ÷ Imposed
In water	5·36 (0·28)	3·21 (0·16)	2·15 (0·22)*	0·35 (0·03)
97%	5·72 (0·35)	2·57 (0·08)	3·17 (0·28)*	0·50 (0·03)
90%	4·72 (0·31)	2·34 (0·07)	2·38 (0·27)*	0·43 (0·04)
80%	3·41 (0·26)	1·60 (0·07)	1·81 (0·21)*	0·46 (0·04)
60%	2·02 (0·15)	1·05 (0·07)	0·97 (0·15)*	0·40 (0·04)
30%	1·52 (0·15)*	0·86 (0·06)*	0·66 (0·09)*	0·36 (0·04)
0%	1·07 (0·07)*	0·84 (0·07)*	0·23 (0·09)*	0·21 (0·04)*

The values of the probable error are smaller for the recovery than for the imposed extension. This indicates less variability from hair to hair of the elastic strain than of the total strain. For the latter, a greater mean value is obtained for 97% R.H. than for saturation. This is possibly a sampling error.

It will be seen that the imposed extension is more than five times as great, and the recovery about four times as great, at saturation as at dryness.

Young's Modulus—We have seen that the hairs behave very differently from a collection of metal wires, in that the visually coarsest hairs do not have a correspondingly small extension, and two causes have been suggested for this, first that visual diameter is not correlated with hair weight, this being assumed to measure the elastic material, and secondly that coarse hairs are intrinsically more extensible. In such circumstances a calculation of Young's Modulus for a hair seems a somewhat arbitrary process. We may however consider this quantity as a statistical magnitude, very variable for different hairs but having at any humidity a mean value characteristic of the material of which the hairs are made. There is a further restriction in the generality of the significance of the magnitude due to the fact that the extension and recovery have been measured for a single load under peculiar conditions of time.

To calculate Young's Modulus, it is necessary to calculate the *stress* or force per unit area of the cross section of the hair and divide by the *strain* or extension of unit length (% extension ÷ 100). A statistical Young's Modulus might be calculated in many different ways. The method adopted

here is to calculate (1) a mean area of a hair from the inverse mean square of the inverse of the observed diameter, (2) the stress by dividing this into the load (400 mg.), (3) the modulus, and finally (4) the average of the 25 values at any humidity. These average values are given in Table IV.

Table IV

R.H. %	Zero	30	60	80	90	97	100
Young's Modulus (dynes/cm.$^2 \times 10^{-10}$)							
Loading	6·38	5·11	2·86	1·59	0·97	0·68	0·62
Recovery	8·81	8·50	4·79	2·82	1·68	1·33	1·00

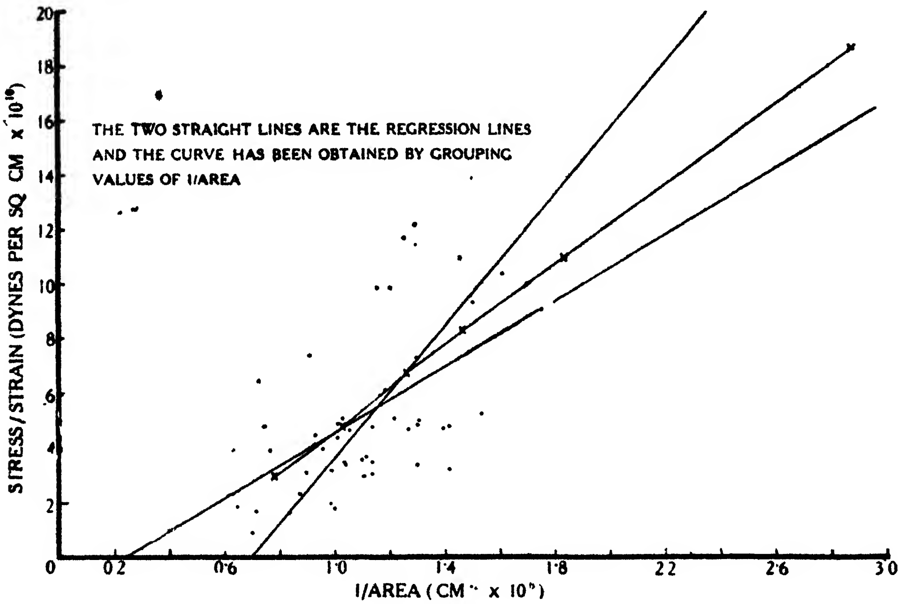

FIG. 4

Correlation between Stress/Strain and 1/Area—There is in general good correlation between the individual value of stress/strain and the diameter of the hairs. As, however, the stress/strain value is a derived quantity, the values found are given below in Table V without any further discussion. The values, except those marked with an asterisk, are all significant in the sense that they indicate that the finer hairs give greater values for stress/strain. Fig. 4 shows the "imposed" stress/strain data for the group of 50 hairs at zero R.H. in a similar way to Fig. 1.

Table V

Correlation Coefficients between Stress/Strain and 1/area

Number of hairs in group ...	50	25	25	25	25	25	25	25
R.H.	0	0	30	60	80	90	97	Water
"Imposed" values	0·70	0·17*	0·64	0·21*	0·41	0·41	0·39	0·44
"Recovery" values	0·73	0·45	0·49	0·45	0·43	0·54	0·62	0·31*

THE HELICAL SPRING CONCEPTION OF A COTTON HAIR

It has been suggested that the extensions of cotton hairs find an explanation if the structure be regarded as that of a helical wire spring (or springs).

The extension of such a spring per unit length is given by—

$$S = \frac{Pr^2}{\pi a^4}\left(\frac{4 \sin^2 \varphi}{E} + \frac{2 \cos^2 \varphi}{\eta}\right)$$

where r = radius of spring, φ = angle of spring to the circular section plane, a = radius of wire, P = force, E = Young's Modulus of wire, η = rigidity of wire. The equation may also be written—

$$S = \frac{4Pr^2 (1 + \sigma \cos^2 \varphi)}{\pi a^4 E}$$

where σ = Poisson's ratio. P is constant in the experiments in this paper, so that we are left with possible variations of r, φ, a, σ, and E. It is clear we have more variables than are necessary to explain the facts.

Choosing the most likely, keeping E, a, and σ constant, we may have—

$$S = K_1 r^2 (1 + \sigma \cos^2 \varphi) \qquad \text{(i)}$$

when φ is assumed constant, or if we assume T turns per unit length (constant)

$$S = K_1 r^2 \left(1 + \frac{\sigma\, 4\pi^2 r^2 T^2}{1 + 4\pi^2 r^2 T^2}\right) \qquad \text{(ii)}$$

For case (i) the extension is proportional to the apparent area, if we suppose the number of such springs to be proportional to the apparent area also, then the extension becomes independent of the area.

For case (ii) the extension is more rapid and making the same assumption as to the number of springs the extension will increase with the apparent area.

Referring to the hair, the hypothesis thus runs as follows—The helical fibrils in the outer layer or layers have the largest Young's Modulus and rigidity, and carry most of the load. In these hairs of larger diameter the outer fibrils are more extensible than in finer hairs, owing to increase of r and probable decrease of φ, so that though more total fibrils may be present to carry the load, the hair extension under constant load is not reduced and may be increased in some circumstances.

The author is indebted to Mr. L. H. C. Tippett for advice and assistance in the statistical analysis of the results. Most of the observations have been made by Mr. W. Bostock and Mr. F. G. Wilde.

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Didsbury

CORRIGENDUM

"The Determination of the Viscosity of Cuprammonium Solutions of Cellulose"

By J. Tankard, B.Sc., A.T.I., and J. Graham

In this article, which appeared on pages T260–T266 of the June issue of this *Journal*, errors occurred by inadvertence which it is desired to correct.

On page T261, 5 lines from the bottom—"1·4 log viscosity" should read "$\bar{1}$·4 log viscosity."

On page T263, 7 lines from the top—"strontium nitrate at 20° C." should read "cobalt chloride at 15° C."

THE JOURNAL OF THE
TEXTILE INSTITUTE
TRANSACTIONS

24—STUDIES IN THE SAMPLING OF COTTON FOR THE DETERMINATION OF FIBRE-PROPERTIES
PART I—INTRODUCTORY AND EXPERIMENTAL
PART II—FREQUENCY-CURVES FOR VARIOUS FIBRE-PROPERTIES

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SUMMARY

Part I

It is pointed out that for the determination of the value of any fibre-property of a cotton, a small sample has to be selected for the experiment. Three questions, therefore, arise, viz.—(1) How we may obtain a satisfactory sample, (2) how many fibres constitute a satisfactory sample, (3) what is the degree of reliability of the results obtained for the value of a fibre-property? The present investigation has therefore been undertaken primarily with a view to obtaining satisfactory answers to these three questions for the following fibre-properties—length, width, number of convolutions, strength, and rigidity. The tests of these properties have been made on some 3,000 fibres of Surat 1027 A.L.F., 1926–27; the description of these tests and the discussion of the results is divided into four parts, the first two parts forming the present paper. Part I is introductory, and contains also a description of the experimental methods used for the measurement of the fibre-properties; Part II deals with the frequency-curves for the various fibre-properties; Part III will deal with the three questions of sampling in the light of the results discussed in Part II; and Part IV will deal with the inter-relationship of the different fibre-properties.

Part II

The answers to the questions formulated in Part I depend upon the manner of distribution of the test-values. Frequency-polygons are drawn to indicate the various frequency-distributions. But as the results obtained relate only to comparatively small samples, theoretical continuous frequency-curves have been drawn by a recognised method to give the closest possible degree of fitting to the frequency-polygons. It is found that the frequency-distributions for fibre-length and convolutions are moderately symmetrical and nearly normal; for fibre-width, symmetrical and practically normal; for fibre-strength, moderately asymmetrical; and for fibre-rigidity, extremely asymmetrical. The causes of the asymmetrical distributions of fibre-strength and fibre-rigidity are discussed at some length and are finally ascribed either to a change in the external conditions of growth during the life-history of the plant, or to the mutual interference of the fibres under the ordinary conditions of their growth.

An appendix is given explaining various statistical terms and methods used in curve-fitting, with detailed examples of their applications to fibre-properties.

PART I—INTRODUCTORY AND EXPERIMENTAL

(1) Introduction

The central problem of the Technological Laboratory is the ascertaining of the relation that exists between the spinning value of a cotton and the fibre-properties of that cotton. It has been the custom at the Laboratory from the beginning to subject every cotton submitted for examination to a series of fibre tests as well as to the spinning test. It is hoped in this way to accumulate data of sufficient quantity and accuracy to enable the solution

of the central problem to be attained. Undoubtedly, the greatest difficulty in the achievement of this end is the extreme variability of cotton fibres, even in a single sample of a pure strain grown under particular conditions; still greater variability is experienced in an impure strain or in a mixture of fibres of a single strain grown under various conditions.

The great variability of the raw material leads to difficulties in sampling, so that, as was pointed out by one of us[1] in "The Foundations of Yarn Strength and Yarn Extension," the full consideration of that problem embraces also a consideration of sampling methods and errors. In order to test the fibre-properties of any given variety it is necessary to select a number of fibres to represent the bulk of the fibres in question. Now a single bale of Indian cotton contains from 25,000,000,000 to 75,000,000,000 fibres; hence owing to the smallness of the cotton fibre as a unit, the difficulty presented by the variability of the fibres is greatly accentuated by the difficulty of selecting a representative sample. In seeking to determine these fibre-properties, therefore, we are confronted with the following questions—

(1) How may we obtain a satisfactory sample ;
(2) How may fibres constitute a satisfactory sample ;
(3) What is the degree of reliability of the results obtained for the value of a fibre-property ?

The formulation of these questions shows at once that the test-results obtained for any one fibre-property must be subjected to an adequate statistical treatment.

A satisfactory sample is obviously one which is completely representative of the bulk from which it is drawn. The obtaining of a satisfactory sample is a matter of practical manipulation; at the same time, statistical methods may be applied in order to ascertain the likelihood of the sample being representative. The answers to the second and third questions depend upon the variability of the sample. It is important, therefore, to note exactly in what manner the variability occurs; this is found by suitably classifying the results when they are obtained, and then plotting a curve to show the frequency-distribution of the property. Fig. 4 is an example of such a frequency-distribution for 3,000 strength tests; the 3,000 tests have been classified to show the numbers falling in the successive intervals 0–0·9, 1·0–1·9, 2·0–2·9, 3·0–3·9, etc.; the number falling in each interval has been plotted, and is shown as belonging to the mid-point of the interval of strength, the strength values being shown on the X-axis, and their frequencies along the Y-axis. Now the answers to the three questions referred to above depend on the form which the frequency-curve takes in any given case; in an earlier paper,[2] explaining the different methods of indicating the dispersion of the results, was also described the method of determining the number of specimens constituting a satisfactory sample *provided the test-values have a "normal" frequency-distribution.* Some results quoted for fibre-strength (200 values) were shown to have a skew distribution, and it was stated that in such a case the formulæ for probable errors, etc., could only apply approximately. Fig. 4 also represents a skew distribution for fibre-strength, and in this case we cannot legitimately apply the method depending on the probable error calculated as if the distribution were "normal." Hence the first object of the present investigation was to determine accurately the form of the frequency-distribution of each property, for which purpose it was necessary to make a large number of tests in each case.

It is seldom indeed that textile tests are made in sufficient numbers to make it possible to ascertain the form of the frequency-distribution of the results with any degree of accuracy. The curves published for cotton yarns by Andrews and Oxley[3] appear to be the only curves so far published relating to numbers of tests extending to some thousands. Yet if it is desirable to make tests on cotton yarn by the thousand in order to obtain an accurate frequency-curve, it is even more necessary for single cotton fibres, as their variability is far greater than that of cotton yarns. Frequency-curves for fibre properties have been obtained by various workers; thus, Barratt[4] has given the frequency-distributions of the following properties of cotton fibres—length, diameter, breaking load, and extension at break—and has fitted to them curves derived from a formula due to Bateman.* But in most cases it is only by courtesy that Barratt's theoretical curves can be said "to fit" his experimental curves, no doubt because the number of tests employed in the determination of each fibre-property was only 100—a number much too small for the accurate determination of the frequency distribution; moreover, there is no justification for his use of the Poisson formula rather than the normal or other possible type of curve.

Miss Clegg[5] has also given a number of frequency-distributions for the breaking loads of single cotton fibres. Each of these diagrams is based on the results of some 200 tests; however, she does not make any attempt to fit theoretical frequency-curves to her results. In a paper dealing with "Variability as a Problem of Textile Testing," Peirce[6] gives a table in which he includes two sets of results for the breaking load of cotton hairs. But here again, only 200 tests were made in each case, so that the determination of the type of frequency-curve cannot be regarded as at all trustworthy.

The present investigation has therefore been undertaken primarily with a view to obtaining satisfactory answers to the three questions, formulated above, for the following fibre-properties—length, width, number of convolutions, strength, and rigidity. Tests of these properties have accordingly been made on some 3,000 fibres; these tests have an added value because the tests for each property have been made on the same individual fibres, so that the test-results have also provided the material for an investigation into the relationship existing between these various properties.

The description of these tests and the discussion of the results obtained is divided into four parts, the first two parts forming the present paper. Part I is introductory, and contains also a description of experimental methods used for the measurement of the fibre-properties; Part II deals with the frequency-curves for the various fibre-properties; Part III will deal with the three questions of sampling enumerated above, in the light of the results discussed in Part II; Part IV will deal with the inter-relationships of the different fibre-properties.

(2) Experimental

Material—The cotton selected for experimental investigation was Surat 1027 A.L.F. (1925–26), as previous tests had shown that the individual test-results of this cotton displayed great variation. In general, 4,000 fibres were examined for the various fibre-properties; but the tests on the first 1,000 fibres did not include any measurements of the convolutions, and the tests on the fourth 1,000 fibres did not include measurements of the fibre-width

* Bateman's formula is the same as that enunciated by Poisson in 1837.

and strength. Hence the material available for statistical analysis comprised the following numbers of test-results—

(1) Fibre-length, 4,000.
(2) Fibre-rigidity, 4,000.
(3) Fibre-width, 3,000.
(4) Fibre-strength, 3,000.
(5) Convolutions, 3,000.

Sampling—It is hardly too much to say that sampling constitutes the most important part of any quantitative investigation of fibre-properties, for, if care be not taken that the sample is representative, the results obtained must be quite untrustworthy. In the present experiments, in order that the sample might fairly be representative, small bundles of fibres were taken from different parts of the bale; these small bundles were put together, and from the mass so obtained a sliver was made and repeatedly doubled and drawn by hand, so that the fibres of this sliver were thoroughly mixed together. Two methods were used for selecting individual fibres from this sliver for testing, viz. (1) the individual fibres for testing were picked out singly from different parts of the sliver; this method was discarded after the first 1,000 tests in favour of the more trustworthy second method; (2) small bundles of hairs were taken at random from the prepared sliver, and all the fibres in each bundle were tested separately.

Experimental Procedure—In the first 1,000 tests, each fibre was subjected to the following tests in order—(1) fibre-rigidity; (2) length; (3) fibre-width; and (4) strength. Each of the remaining fibres was subjected to the following tests in order—(1) fibre-width; (2) total number of convolutions; (3) length; (4) fibre-rigidity; and (5) strength.

(i) *Fibre-width and Convolutions*—The hairs were mounted dry on a glass slide (four or five on each slide), and the ends were fastened down with seccotine; during mounting, sufficient tension was applied to straighten the hair. Each fibre was numbered; its fibre-width was determined by measurement under the microscope at ten different places along the fibre. Each measurement was taken mid-way between a pair of convolutions, as it is at this point only that the full width of the fibre is seen under the microscope. The convolutions of each fibre were measured at three places, viz., at the two ends (about 2 mm. at each end), and at the middle portion of the fibre. The sum of these three measurements gave the total number of convolutions per fibre; this procedure was adopted because the fibre-rigidity and strength are determined on the middle portions only, the ends being embedded in wax; hence by using the results for the convolutions present in the middle portions of the fibres, the correlation could be obtained, if desired, between either the fibre-rigidity or strength and the number of convolutions present in the actual test portions of the fibres.

(ii) *Fibre-rigidity and Length*—The fibre-rigidity of each fibre was determined by measuring the time of torsional vibration of a small cylindrical aluminium rod, suspended horizontally at its mid-point by the cotton fibre under test. The value of the fibre-rigidity is calculated from the following formula[7]—

$$R = \frac{8\pi^3 K l}{t^2}$$

where R is the fibre-rigidity in dyne-cms.^{2}; K is the moment of inertia of the suspended rod, l the length of the fibre, and t the period of torsional vibration.

In view of the fact that the rigidity varies tremendously with humidity (the value at 100% R.H. is only about one-quarter of that at 30% R.H.) all the experiments were performed in an enclosed chamber, the relative humidity of which was maintained at constant relative humidity[8] (70%) by means of a solution of calcium chloride, 100 parts of which contain 27 parts by weight of amorphous calcium chloride. From 20 to 25 fibre-pendulums were suspended at a time from a brass stand and allowed to remain in the chamber overnight so as to attain constant humidity; the period of vibration for each fibre was determined the next morning. For setting the aluminium rod into vibration a thin brass wire suitably bent was fixed to a rod passing through the chamber; by manipulating the end of this rod outside the chamber, it could be given both the translatory and rotational movements necessary to cause the brass wire to strike the end of any particular aluminium rod. The length of the fibre was measured by means of a telescope fitted with a micrometer eyepiece.

(iii) *Fibre-strength*—The apparatus used for obtaining the breaking load of single cotton hairs was Barratt's[9] Fibre Balance. Each hair was mounted on two eyelets by means of a mixture of sealing wax and paraffin wax, a length of about 2 mm. being embedded in the wax at each end; except for this, the full length of the fibre was used in each test.

PART II—THE FREQUENCY-CURVES FOR VARIOUS FIBRE-PROPERTIES

The frequency-curves for the different properties are shown in Figs. 1–9; these figs. also include certain theoretical curves which have been calculated according to the system of types developed by Karl Pearson[10]; these theoretical curves are respectively the types which fit most closely to the observation-curves; the actual values of the observed frequencies, together with the theoretical frequencies calculated from the equations to the theoretical curves, are shown in Tables I–VIII. The full understanding of these curves and their derivation requires some acquaintance with statistical methods; for this reason, an explanation of the more important terms used, and a short discussion of the various statistical methods, are given in the Appendix, together with examples of the application of the method.

(1) *Fibre-length*—The frequency-distribution obtained for fibre-length is shown in Fig. 1; it is practically symmetrical and approximately normal. Apart from the normal curve, Pearson's Type II—another symmetrical type—is the theoretical frequency-curve which gives the closest fit to the observed values. The equations for the curves of closest fit, showing the relation between any fibre-length x and its frequency of occurrence, y, were found to be as follows for the normal and Type II curves—

$$\text{Normal curve}: y=976{\cdot}8\, e^{-\frac{x^2}{\cdot 4806}}$$

$$\text{Type II}: y=9618\,.\left(1-\frac{x^2}{11{\cdot}533}\right)^{22\cdot 5}$$

Table I shows the observed frequency-distribution of the 4,000 tests (col. 2) and the corresponding calculated values for the Type II and normal curves (cols. 3 and 5), the observed and calculated "normal" values for the last 3,000 tests (cols. 7 and 8), and also the frequency-distributions of the four sets of successive 1,000 tests (cols. 10 to 13), together with the corresponding calculated values for the Type II and normal curves for 1,000 tests,

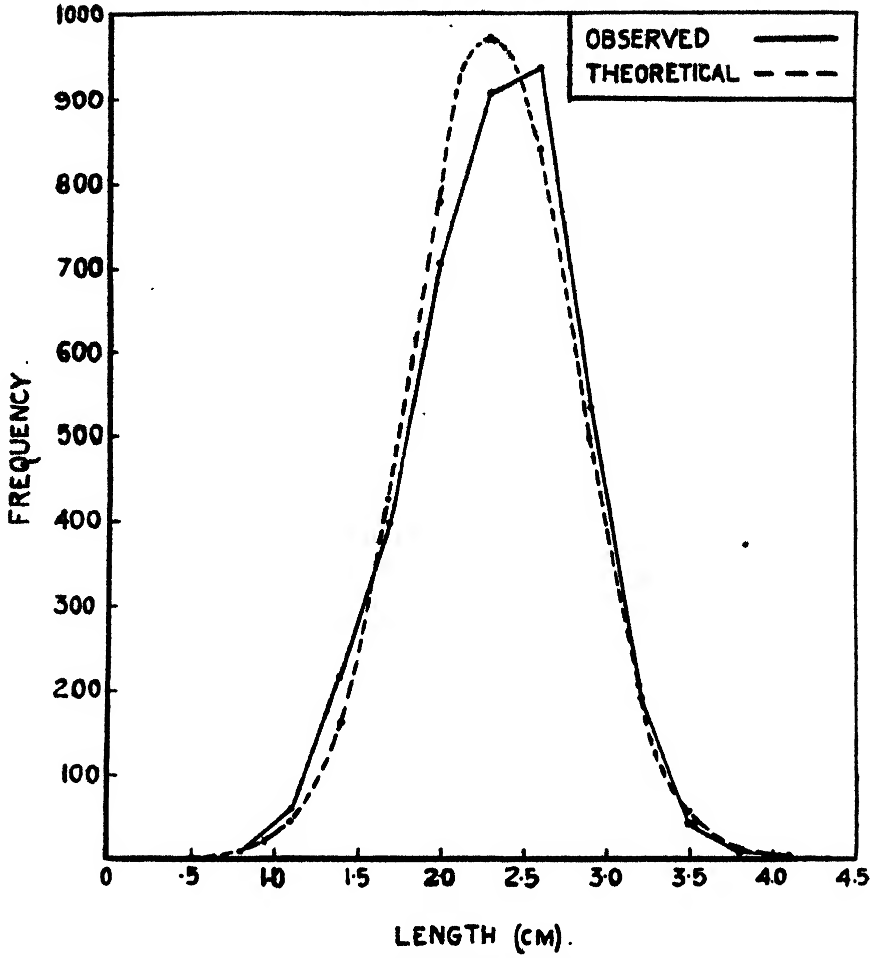

FIG. 1. Frequency-curves for Fibre-length of Surat 1027 A.L.F. (4,000 Tests).

these being derived from the theoretical frequency-distribution fitted to the results of 4,000 tests. The deviations between observed and calculated values are also given for the 4,000 tests and 3,000 tests respectively.

From this table it appears that Type II gives a slightly better fit than the normal curve, as the percentage errors in the ordinates for the two curves are 10·00 and 10·41 respectively; this difference, however, can be regarded as negligible. Fig. 1 illustrates the degree of fit of the normal curve to the observed frequency-distribution; it will be noted that at several points there are marked divergencies.

Cols. 10 to 13 of Table I show how marked is the divergence of the first 1,000 tests from the other three sets. As already pointed out (page T328), the sampling method used in the selection of the fibres for the first 1,000 tests was different from that used for the subsequent tests, and is likely to have been biassed in favour of the longer fibres; this is borne out by the fact that the mean value for the first 1,000 tests, 2·54 cm., is over 10% greater than the means of the second, third, and fourth 1,000 tests, which yield practically the same mean, their values being 2·27, 2·29, and 2·22 cm. respectively. If,

Table I

'requ distributions of Fibre-length

Class-interval	4, 000 Tests					Last 3,000 Tests			Sets of 1,000 Tests					
	Ob-served	Type II	Devia-tion	Normal	Devia-tion	Ob-served	Normal	Devia-tion	Observed				Type II	Normal
									First 1,000	Second 1,000	Third 1,000	Fourth 1,000		
0·4–0·6	0	0	0·0	0·8	0·8	0	1·5	1·5	0	0	0	0	0	0·2
0·7–0·9	5	5·9	0·9	7·6	2·6	4	10·1	6·1	1	3	1	0	1·5	1·9
1·0–1·2	59	40·4	18·6	42·0	17·0	56	47·9	8·1	3	30	16	10	10·1	10·5
1·3–1·5	216	166·2	49·8	161·8	54·2	213	164·4	48·6	3	76	60	77	41·3	40·4
1·6–1·8	397	440·0	43·0	427·8	30·8	359	386·0	27·0	38	101	98	150	110·0	106·7
1·9–2·1	703	777·6	74·6	778·9	75·9	578	630·1	52·0	125	174	188	216	194·4	194·7
2·2–2·4	907	951·9	44·9	972·9	65·9	690	716·1	26·1	217	209	252	229	238·0	243·2
2·5–2·7	941	836·4	104·6	839·2	101·8	605	568·0	37·0	336	210	217	178	209·1	209·8
2·8–3·0	532	505·4	27·6	497·3	34·7	339	314·7	24·3	193	117	119	103	126·3	124·3
3·1–3·3	190	208·5	18·5	202·5	12·5	128	120·6	7·4	62	53	43	32	52·1	50·6
3·4–3·6	41	57·1	16·1	56·7	15·7	20	32·3	11·3	21	12	5	3	14·3	14·2
3·7–3·9	7	7·3	0·3	10·9	3·9	6	6·1	0·1	1	4	1	1	1·8	2·7
4·0–4·2	2	1·0	1·0	1·5	0·5	2	0·8	1·2	0	1	0	1	0·2	0·4

therefore, we consider the last 3,000 tests separately, their frequency-distribution gives an even closer fit to the normal curve, as may be seen from cols. 7–9 of Table I; the values in col. 8 are for the normal curve.

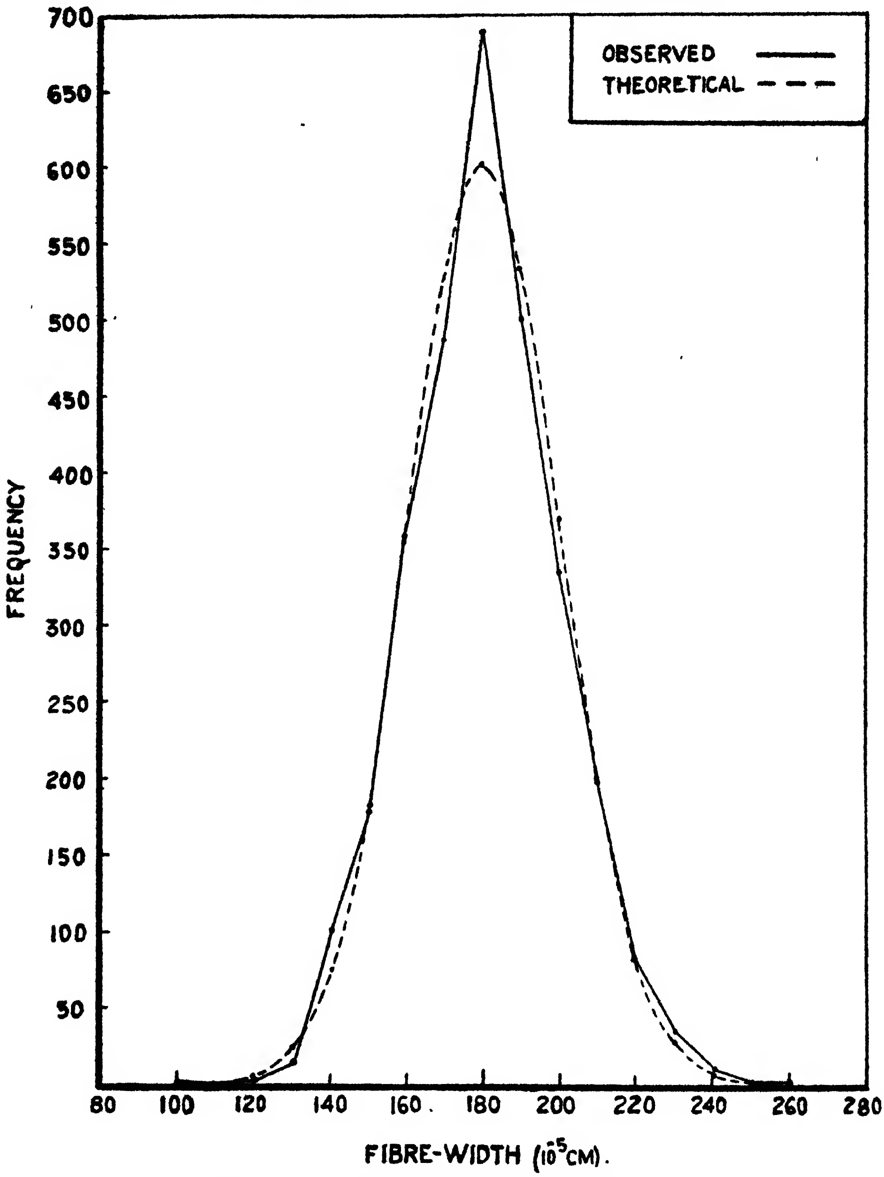

FIG 2. Frequency-curves for Fibre-width of Surat 1027 A.L.F. (3,000 Tests).

(2) *Fibre-width*—The frequency-distribution obtained for fibre-width is shown in Fig. 2; the distribution does not depart much from the normal curve, apart from which Pearson's Type IV is the theoretical frequency-curve which gives the closest fit to the observed values. The equations for the curves of closest fit showing the relation between any fibre-width x and the frequency of its occurrence y, were found to be as follows for the normal and Type IV curves—

Normal curve : $y=600{\cdot}8\,e^{-\frac{x^2}{793\cdot7}}$

Pearson's Type IV : $y=366{\cdot}399\left\{1+\frac{x^2}{(11{\cdot}549)^2}\right\}^{-18\cdot8225}\times e^{-6\cdot2538\tan^{-1}\frac{x}{11\cdot549}}$

Table II shows the observed frequency-distribution of the 3,000 tests, and the corresponding calculated values for the normal and Type IV curves, and also the frequency-distributions of the three sets of successive 1,000 tests.

Table II

Frequency-distributions of Fibre-width

Mid-point of Class 10^{-5} cm.	300 Tests					Sets of 1,000 Tests				
						Observed				
	Ob-served	Nor-mal	Devia-tion	Type IV	Devia-tion	First 1,000	Second 1,000	Third 1,000	Nor-mal	Type IV
99·5	2	0·2	1·8	0·2	1·8	1	0	1	0	0
109·5	0	1·2	1·2	1·1	1·1	0	0	0	0	0
119·5	2	6·1	4·1	5·3	3·3	1	1	0	2	2
129·5	16	24·5	8·5	21·6	5·6	9	3	4	8	7
139·5	98	77·0	21·0	71·0	27·0	66	15	17	26	24
149·5	181	187·8	6·8	183·9	2·9	84	32	65	63	61
159·5	359	356·0	3·0	364·3	5·3	146	81	132	119	121
169·5	488	524·4	36·4	544·9	56·9	195	127	166	175	182
179·5	690	600·8	89·2	614·6	75·4	255	214	221	200	205
189·5	501	534·7	33·7	527·1	26·1	124	205	172	178	176
199·5	332	369·9	37·9	351·2	19·2	61	161	110	123	117
209·5	198	198·9	0·9	187·4	10·6	45	89	64	66	63
219·5	81	83·1	2·1	82·4	1·4	7	48	26	27	27
229·5	37	26·5	10·5	31·0	6·0	5	16	16	9	10
239·5	11	6·8	4·2	10·2	0·8	1	5	5	2	3
249·5	3	1·3	1·7	2·7	0·3	0	2	1	0	1
259·5	1	0·2	0·8	0·9	0·1	0	1	0	0	0

From this table it appears that there is practically no difference between the fit of the normal and Type IV curves, as the percentage errors in the ordinates for the two curves are 8·79 and 8·13 respectively—a difference which is negligible. It is therefore concluded that the fibre-width distribution can be assigned to the normal curve without appreciable error.

(3) *Convolutions*—The frequency-distribution obtained for the number of convolutions per fibre is shown in Fig. 3; the distribution does not depart much from the normal curve, apart from which Pearson's Type IV is the theoretical frequency-curve which gives the closest fit to the observed values. The equations for the curves of closest fit showing the relation between any number of convolutions x and the frequency of its occurrence y, were found to be as follows for the normal and Type IV curves—

Normal curve : $y=580{\cdot}8\,e^{-\frac{x^2}{2(30\cdot9)^2}}$

Pearson's Type IV : $y=9{\cdot}583\times10^{-27}\left\{1+\frac{x^2}{(36{\cdot}05)^2}\right\}^{-47\cdot7575}\times e^{-122\cdot8\tan^{-1}\frac{x}{36\cdot05}}$

Table III shows the observed frequency-distribution of the 3,000 tests and the corresponding calculated values for the Normal and Type IV curves, and also the frequency-distributions of the three sets of successive 1,000 tests.

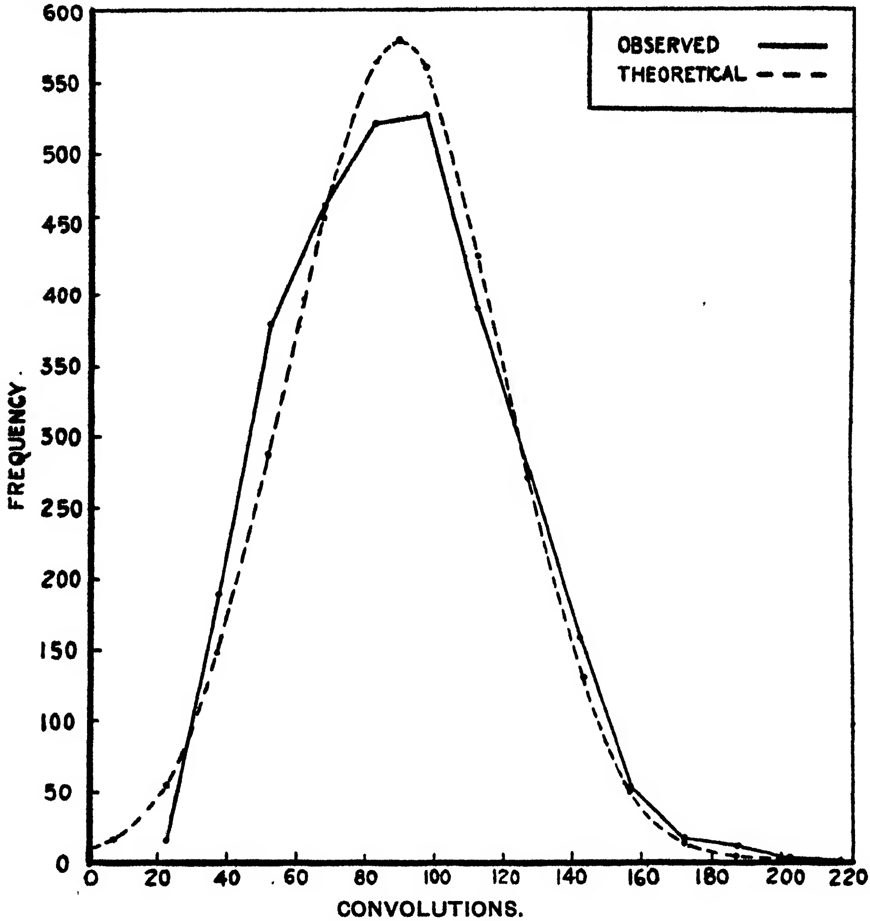

FIG 3. Frequency-curve for Convolutions of Surat 1027 A.L.F. (3,000 Tests).

Table III
Frequency-distributions of Convolutions

Class	3,000 Tests					Sets of 1,000 Tests				
						Observed				
	Observed	Type IV	Deviation	Normal	Deviation	First 1,000	Second 1,000	Third 1,000	Normal	Type IV
15– 29	16	40·6	24·6	56·2	40·2	0	4	12	19	14
30– 44	192	144·1	47·9	148·6	43·4	38	68	86	50	48
45– 59	379	322·5	56·5	285·8	93·2	108	104	167	95	107
60– 74	462	499·6	37·6	453·0	9·0	166	130	166	151	167
75– 89	520	600·6	80·6	566·9	46·9	184	176	160	189	200
90–104	527	547·8	20·8	561·0	34·0	196	176	155	187	183
105–111	390	396·8	6·8	427·9	37·9	144	136	110	143	132
120–134	273	233·6	39·4	270·3	2·7	93	100	80	90	78
135–149	157	128·4	28·6	131·8	25·2	47	74	36	44	43
150–164	52	58·0	6·0	50·7	1·3	20	15	17	17	19
165–179	18	19·0	1·0	15·4	2·6	1	11	6	5	6
180–194	11	9·6	1·4	3·8	7·2	3	3	5	1	3
195–209	2	3·3	1·3	0·7	1·3	0	2	0	0	1
210–224	1	1·0	0·0	0·1	0·9	0	1	0	0	0

From this table it appears that there is practically no difference between the fit of the normal and Type IV curves, as the percentage errors in the ordinates for the two curves are 11·53 and 11·75 respectively—a difference which is negligible. It is therefore concluded that the distribution of the number of convolutions can be assigned to the normal curve without appreciable error. Most of the divergencies between the actual and theoretical frequency-distributions occur near the tails of the normal curve, and especially towards the dwarf side of the mean. The explanation of this feature is that there are very few fibres which have a small number of convolutions—there is no fibre out of the 3,000 tested which has less than 15 convolutions, and there are only two fibres which have between 15 and 24 convolutions; it is on this account that the tail to the left of the mean is missing, and that the curve begins abruptly in Fig. 3.

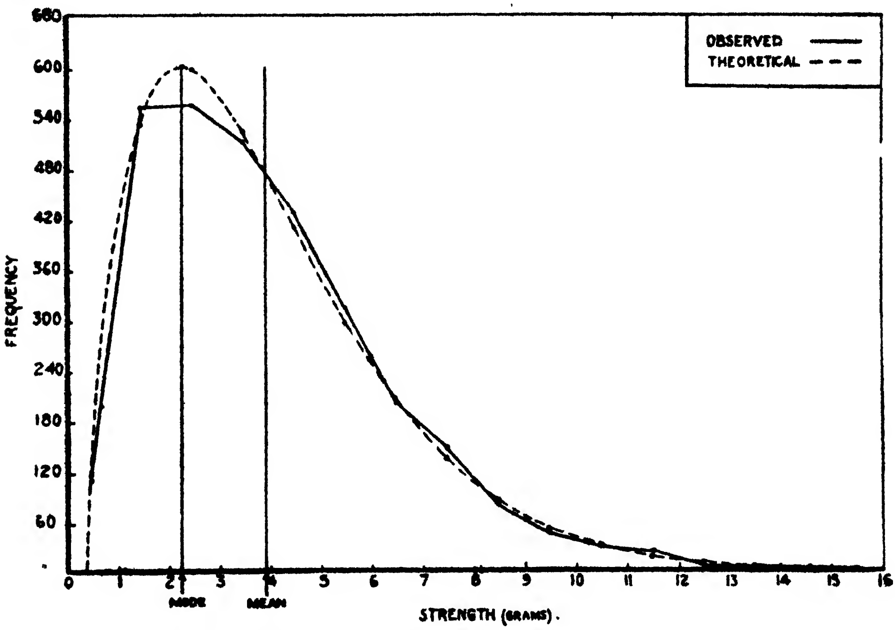

FIG. 4. Frequency-curve for Fibre-strength of Surat 1027 A.L.F. (3,000 Tests).

(4) *Fibre-strength*—The frequency-distribution obtained for fibre-strength is shown in Fig. 4. The most striking feature about the frequency-curve is its asymmetry, showing a well-marked predominance of weak fibres. It was found that the observation-curve would be well fitted by a theoretical curve of Pearson's Type I, having the following equation—

$$y = 599{\cdot}3\left(1 + \frac{x}{1{\cdot}8777}\right)^{0.876716}\left(1 - \frac{x}{29{\cdot}1947}\right)^{13.631284}$$

In this equation y represents the frequency of any strength x, expressed in grammes; the origin for the curve is at the "mode," which is the value of the strength having the highest frequency (see Appendix, page T350); in this case the modal strength is 2·2552 grammes.

Values of y for different values of x have been calculated from this equation and are given in Table IV.

Table IV

Frequency-distribution of Strength-values of 3000 fibres of Surat 1027 A.L.F. (1925-26).

Strength-class grams	Observed Frequency	Theoretical Frequency		Sets of 1,000 Tests		
	3,000 Tests	3,000 Tests	1,000 Tests	First 1,000	Second 1,000	Third 1,000
0·0– 0·9	117	127·3	41	38	41	38
1·0– 1·9	550	531·5	177	182	203	165
2·0– 2·9	552	596·5	199	184	180	188
3·0– 3·9	510	522·1	174	172	179	159
4·0– 4·9	424	407·2	136	156	131	137
5·0– 5·9	312	295·6	99	105	93	114
6·0– 6·9	199	202·8	68	65	53	81
7·0– 7·9	149	132·9	44	46	55	48
8·0– 8·9	74	82·9	28	20	25	29
9·0– 9·9	46	50·5	17	14	13	19
10·0–10·9	29	29·4	10	7	7	15
11·0–11·9	23	16·4	5	7	10	6
12·0–12·9	6	8·8	3	2	4	0
13·0–13·9	4	4·5	1	1	2	1
14·0–14·9	4	2·2	1	1	3	0
15·0–15·9	1	1·0	0	0	1	0
Mean	3·91 ±0·029			3·86 ±0·048	3·88 ±0·052	4·04 ±0·050
Distance between mean and mode	1·655 ±0·104			1·699 ±0·172	1·823 ±0·2176	1·6375 ±0·1680
Standard deviation	2·357 ±0·0205			2·272 ±0·0343	2·482 ±0·0374	2·358 ±0·0355
Skewness	0·701 ±0·040			0·748 ±0·070	0·734 ±0·085	0·695 ±0·069

In this table, col. 1 shows the various class-intervals of strength, increasing by 1 gram in descending the table; cols. 2 and 3 show the observed and theoretical frequencies in the corresponding class-intervals of col. 1. Merely by general comparison of the theoretical and observed frequencies, and by inspection of the theoretical and actual frequency-curves superposed in Fig. 4, it appears that the distribution of the strength of the 3,000 fibres of Surat 1027 A.L.F. is excellently described as being of Type I; and this conclusion is completely confirmed by the application of the more accurate methods described in the Appendix (page T366) for the determination of the goodness of fit.

It is interesting to note what the results would have been if we had tested only 1,000 fibres. For this purpose the 3,000 results have been divided into three successive groups of 1,000 each; col. 4 in Table IV shows the theoretical frequency-distribution of 1,000 results, based on that of the 3,000 results; cols. 5, 6, and 7 show the observed frequencies of the three sets of 1,000 results. At the bottom of Table IV are given the several values of the mean, the distance between the mean and the mode, the standard deviation, and the skewness; from an examination of these values and their associated probable errors, we conclude that the constants are not significantly different for sets of 1,000 tests and 3,000 tests.

The strongly marked asymmetry of the strength-distribution of Surat 1027 A.L.F., found above for single whole fibres whether tested in successive groups of 1,000 or in a single group of 3,000, is borne out by an analysis of over 5,000 fibre-strength tests of the same character made in the Technological Laboratory by Mr. Hari Rao Navkal, using a different instrument (the Balls Magazine Hair Tester), and a different test-length, viz. 1 cm., instead of the whole fibre used in the present investigation. Mr. Navkal has also made tests on two other standard cottons, viz. Cambodia Co. 1 (1923–24) and Dharwar 1 (1924–25), using the same instrument, but making only 1,000 tests in each case. In every case it has been found that a theoretical frequency-curve of Type I fits the observed frequencies very well.

The asymmetry of the frequency-curves for strength is well brought out by the numerical values obtained for the skewness, as obtained by Pearson's method; this method consists of dividing the difference between the mean and the mode by the standard deviation (see Appendix, pages T350, T352, T355). That all the curves belong to Type I is indicated by Pearson's "criterion of type,"[11] k_2, which for Type I must have a value that is negative. That all the curves are decidedly skew and of Type I is clear from the values of their frequency-constants given in Table V; this table also includes the values for two other cottons, Punjab-American 289F and Aligarh A.19, the test-results for which have been obtained by Mr. H. N. Dutt using 1 cm. test-lengths in a Balls Magazine Hair Tester.

Table V

Frequency-constants for the Fibre-strengths of some Standard Indian Cottons

Frequency-constants	Surat 1027 A.L.F. (3,000 tests)	Surat 1027 A L.F. (5,010 tests)	Dharwar 1 (1,000 tests)	Cambodia Co. 1 (1,000 tests)	Punjab American 289F (5,000 tests)	Aligarh A.19 (1,000 tests)
	grams	grams	grams	grams	grams	grams
Mean	3·91	4·898	4·677	4·376	4·154	6·631
Mode	2·255	2·843	3·702	3·360	3·191	5·525
Mean – Mode ...	1·655	2·055	0·975	1·016	0·963	1·106
Standard deviation	2·357	2·862	2·200	2·248	2·153	3·265
Skewness ...	0·702	0·718	0·443	0·452	0·447	0·339
Criterion of Type (K_2) ...	−1·481	−0·266	−0·211	−0·286	−1·875	−0·243
Type of Frequency Curve	Type I	Type I	Type I	Type I	Type I	Type I

It is interesting to note that Surat 1027 A.L.F. has given practically the same values for skewness for 3,000 fibres tested on the whole length of the fibre in the Barratt Fibre Balance as for 5,010 fibres tested on 1 cm. length in the Balls Magazine Hair Tester.

The Standard Indian cottons, when tested year by year, have given very similar frequency-distributions to that of Surat 1027 A.L.F. But all together, only 600 tests are made on each standard cotton of each season, 300 tests being made in the Balls Magazine Tester, and 300 by the O'Neill method. As the number of tests by any one method is comparatively few, it is not surprising that there is a certain amount of difference in the frequency-distributions of the various cottons. Fig. 5 shows the frequency-distributions of six standard cottons of 1927–28, these having been selected to show the range of the divergence. It will be observed that, in spite of their

differences from one another, all the curves except that of Nandyal 14 are decidedly skew. Table VI shows the frequency-constants for the fibre-strengths of these six cottons, arranged in order of increasing mean strength.

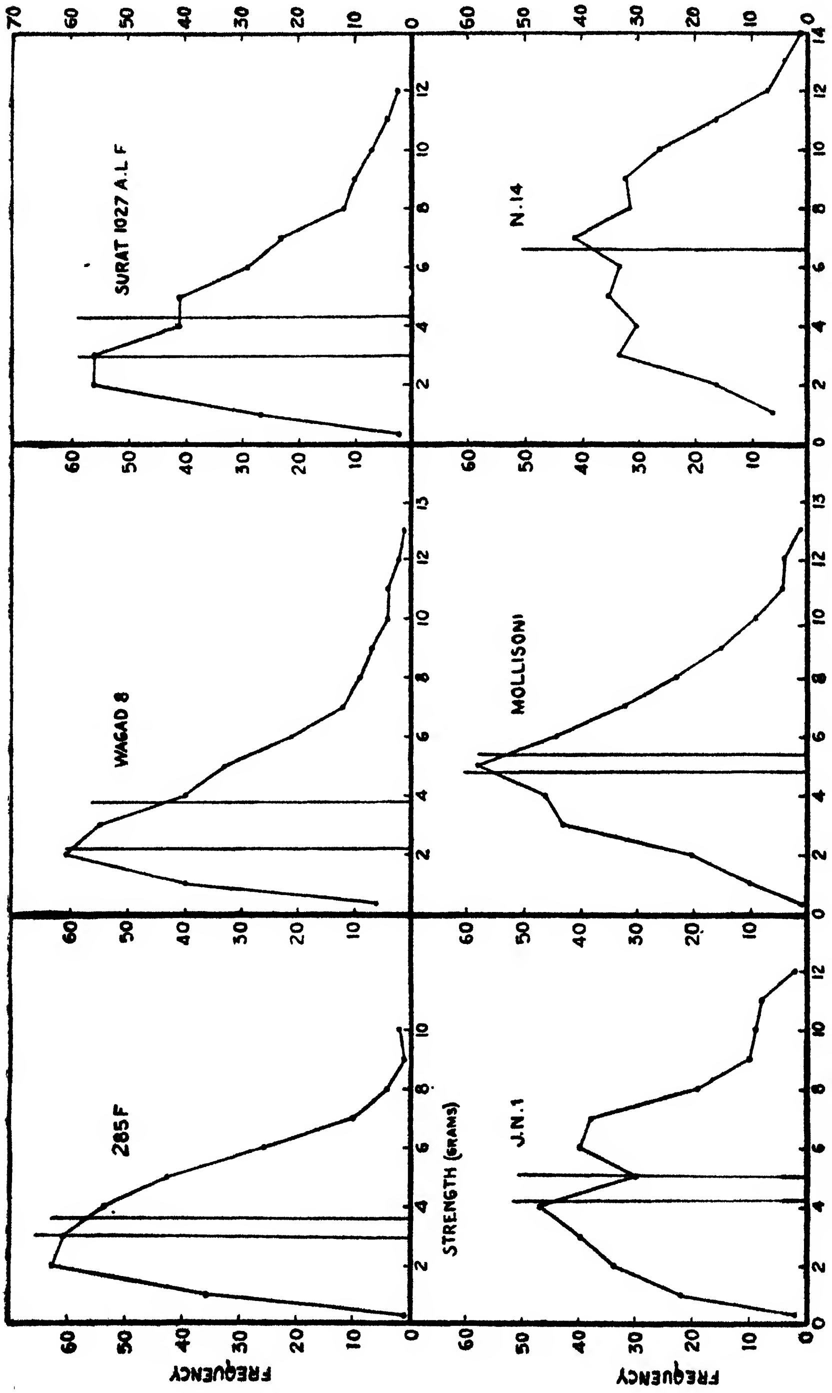

Fig. 5. Frequency-distributions for Fibre-strength of Standard Indian Cottons 1927–1928 (300 Tests).

Table VI

Frequency-constants for the Fibre-strengths of some Standard Indian Cottons, 1927-28 (300 tests in each case)

Cotton	Mean (grams)	Median (grams)	Mode (grams)	Standard Deviation (grams)	Skewness	Upper Quartile (grams)	Lower Quartile (grams)	Distance of Upper Quartile from Mean	Distance of Lower Quartile from Mean	Quartile Deviation
P.A. 285F ...	3·581	3·378	2·972	1·806	·3372	4·800	2·157	1·219	1·424	1·322
Wagad 8 ...	3·840	3·286	2·178	2·484	·6674	5·133	2·005	1·293	1·835	1·564
Surat 1027 A.L.F. ...	4·357	3·891	2·959	2·478	·5642	5·878	2·416	1·521	1·941	1·731
J.N.1 ...	5·050	4·750	4·150	2·596	·3466	6·840	3·000	1·790	2·05	1·920
Mollisoni ...	5·389	5·153	4·681	2·405	·2917	6·878	3·626	1·489	1·763	1·626
Nandyal 14 ...	6·606	6·611	6·60	2·858	0	8·812	4·310	2·206	2·296	2·251

From an examination of the frequency-distributions of the other standard cottons of the same season, the following classification can be made—

Similar to 285F: 4F, 289F.

Similar to Wagad 8: Wagad 4.

Similar to 1027 A.L.F.: Cambodia Co. 1, Hagari 25, Cawnpore-American C.A.9, Dharwar 1, Gadag 1.

Similar to J.N.1: Cawnpore K.22.

Similar to Mollisoni: Karunganni C7, Umri Bani.

Similar to Nandyal 14: Aligarh A.19.

It is interesting to note that as the mean value of strength increases, so the skewness of the frequency-curves appears to diminish; but as these frequency-curves are based on comparatively few tests, their form is subject to sampling errors, which are no doubt responsible for the irregularities in some of the curves, and probably for the fact that the skewness for 1027 A.L.F. is only 0·56 whereas for the 1925–26 cotton it was 0·70 (Barratt tester), and 0·72 (Balls tester). Nevertheless, there is a possibility that the degree of skewness of the frequency-curve represents a real property of the particular sample of cotton for the season in question. But whether the frequency-curve for Nandyal 14, which has the highest mean value for strength, can be regarded as an approach to a normal curve, with zero skewness, seems very doubtful; although the curve is fairly symmetrical, having its mean, median, and mode practically coincident, and so having zero skewness, yet the curve cannot be fitted by a true normal curve. Further, although Aligarh A.19 with only 300 tests gives a curve closely resembling that of Nandyal 14, yet, as we have already seen in Table V, the same cotton in another season had a rather higher mean than that of Nandyal 14, and yet possessed a quite considerable skewness.

If we now sum up the results for the frequency-distributions for fibre-strength we see that the dominating feature is the skewness of the distribution. Miss Clegg[5a] found much the same thing and says—"It was generally found on plotting the frequency arrays that the curves were either two-peaked or decidedly skew, as shown by the curves ...... for Trinidad and Punjab-American respectively. Increasing the number of observations did not modify the form of curve, owing to the persistence in the sample of an undue proportion of weak hairs." And again, [5b] "If whole hairs were broken instead of centimetre lengths, the character of the curve would again be different owing to the greater opportunity for weak places to be encountered. The best method, therefore, would appear to be to employ

whole hairs in order to obtain the maximum chance of encountering the weakest place in each, rather than make this chance variable and intangible by employing an arbitrary fraction of the total length." But while our experiments confirm the skewness of the distribution, we find that when we compare the frequency-distribution of any set of 1,000 tests with that of 3,000 tests (Surat 1027 A.L.F.), not only does the form of curve remain unaltered but the variation and asymmetry also remains the same, within the errors of random sampling. Hence the skewness in this case cannot be a consequence of the sampling but must be regarded as a definite physical constant subject to variation due to sampling as are other constants of a frequency-curve (mean, standard deviation, etc.). On the other hand, our experiments lend no support to the suggestion that the skewness of the frequency-distribution is due to testing centimetre-lengths instead of whole fibres, for the frequency-distribution of the 3,000 tests made on complete fibres is almost identical with that of the 5,010 tests made on 1 cm. lengths. Both frequency-curves belong to Pearson's Type I, and the values of skewness and of the coefficient of variation are the same for both. Hence no real improvement in the form of distribution has been obtained by using the whole length of each fibre instead of a centimetre-length.

Turning now to the results given by Peirce[6a] for the frequency-constants of fibre-strength, we note that he assigns both of his examples to Pearson's Type VII, whereas we have almost invariably found Type I to be applicable. However, if the values given by Peirce for β_1 and β_2 are correct, it would appear that Type I or Type II is more applicable to his first illustration and Type II to his second illustration; but in any case the constants given by him are based on 200 observations only, and such a small number of observations must be regarded as untrustworthy for the purpose of deciding on the type to which the frequency-distribution should be assigned.

Finally, we may enquire as to the underlying cause of the skewness of the frequency-distribution of fibre-strength. The skewness in question arises chiefly from the superabundance of weak fibres; to what is this excess of weak fibres due ? There are three possibilities; first, that the growth processes are such that the plant aims, so to speak, at producing this excess of weak fibres; secondly, that although the plant aims at producing fibres having a normal distribution of fibre-strength, an excess of weak fibres is produced by the operation of certain inhibiting environmental factors; and thirdly, that the excess of weak fibres is produced by mechanical damage in ginning.

If the plant aims at producing an asymmetrical distribution there is of course no reason to look elsewhere for the explanation of the type of curve obtained. But if the mode of growth of the fibres and their internal structure be considered, there appears to be no *a priori* reason, apart from external interference with the growth of the fibres, discussed later, for expecting an asymmetrical distribution.

The second possible explanation of the asymmetry is that it arises from differences in the conditions of growth to which different fibres may have been subjected. Even if the fibres on a single seed have normal frequency-distribution for fibre-strength, yet a mixture of fibres from different seeds may have an asymmetrical distribution; for instance, suppose the fibres on one seed have developed normally whereas those on another seed have been subject to malnutrition during their thickening stage, and so are both thin and weak; it is possible that if both types of fibres are present in a mixture

the frequency-distribution of fibre-strength will be asymmetrical owing to an excess of weak fibres. It might be thought that if the asymmetry were due to this cause, a similar asymmetry should exist in the frequency-curves for fibre-length, ribbon-width, and the number of convolutions; but as we have already seen, the frequency-curves for these fibre-properties are very nearly normal. This contrast, however, may be explained by the fact that these fibre-properties would not be greatly affected by environmental changes operating during the period of secondary thickening. It should be noted that an excess of weak fibres may be produced even on a single seed, if a change in the environment leads to differential nutrition of the fibres.

Nevertheless, it is possible that the asymmetry of the fibre-strength frequency-curve has its origin elsewhere. As already pointed out, the strength of the fibre is only a single-point phenomenon of its whole length; it is this characteristic which distinguishes the strength from the three properties just referred to. Now in the course of growth inside the boll, the fibre frequently jostles against neighbouring fibres, the false placenta, or the wall of the boll; and from the chevelure pattern which the lint in a boll is forced to assume as a consequence of the close packing, the fibres are bound to bend and become kinked, and possibly thin-walled, so giving rise to points of weakness. If on account of these conditions of growth a proportion only of the lint hairs have their strength reduced, and if without such weakening the frequency-distribution of fibre-strength would have been symmetrical, then with this weakening the distribution must be rendered asymmetrical, with an excess of weak fibres. Actually, of course, there will be many degrees of weakening of the fibres, but the final position will most probably be the same—an asymmetrical frequency-distribution. And as the fibres of every individual seed are subjected to this type of interference with their growth, it is to be expected in such a case that an asymmetrical distribution will be characteristic of the fibres from a single seed.

Lastly, in the ginning of the cotton there is a tendency for damage to be done to the fibres when being separated from the seeds. If this again affects only a proportion of the fibres, weakening these to a certain extent, a naturally symmetrical distribution will be rendered asymmetrical. It is doubtful, however, whether this factor is anything like so potent as the effect of bends and kinks produced naturally in the fibre in the course of its growth, especially as an asymmetrical distribution is obtained when the lint is carefully removed direct from the kapas by hand, and the possibility of mechanical damage is definitely excluded. It appears therefore that the skewness of the frequency-curve for fibre-strength is to be ascribed either to a change in the external conditions of growth during the life-history of the plant, or to the mutual interference of the fibres under the ordinary conditions of their growth.

(5) *Fibre-rigidity*—The frequency-distribution obtained for fibre-rigidity is shown in Fig. 6, from which it will be seen that the frequency-distribution bears no resemblance whatever to the normal curve. It is in fact extremely asymmetrical, and Pearson's Type I_J gives the closest fit to the observed values. The equation to the curve of closest fit is—

$$y=93880.x^{-0.42846}\times(0{\cdot}47494-x)^{9.8585}$$

with origin at 0·0010 dyne-cm², where the curve starts.

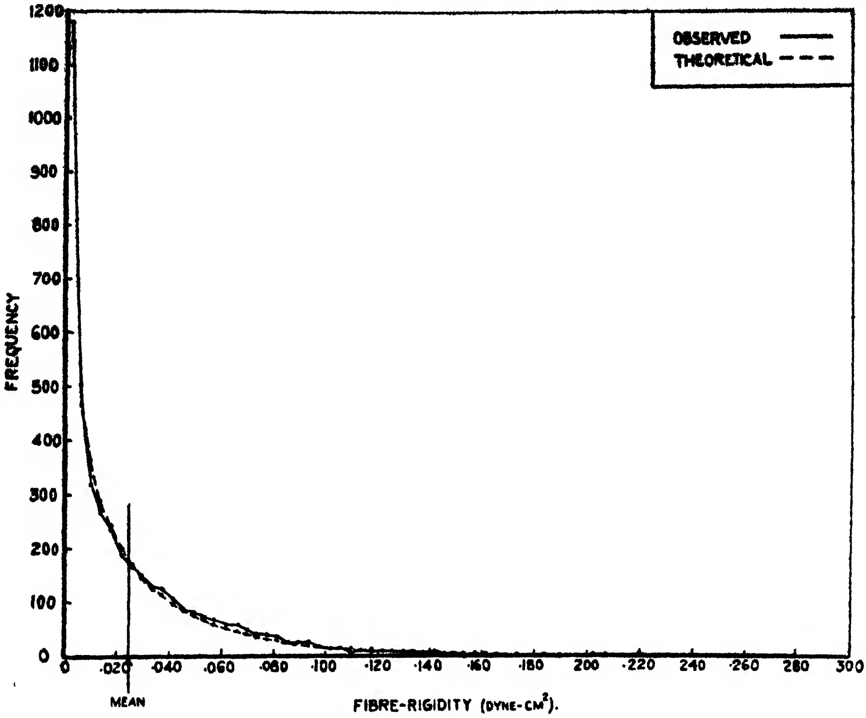

FIG. 6. Frequency-curve for Fibre-rigidity of Surat 1027 A.L.F. (4,000 Tests).

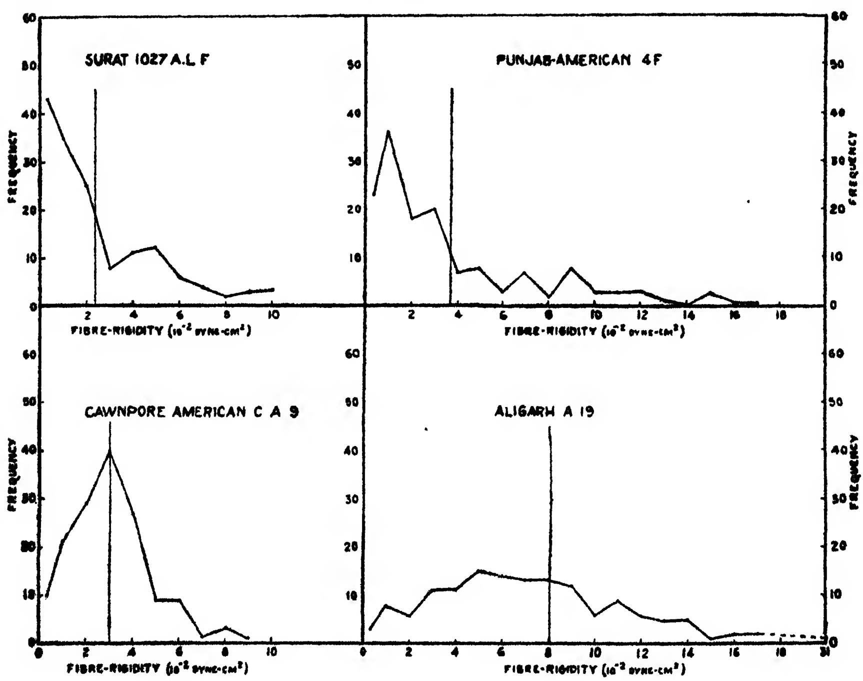

FIG. 7. Frequency-distributions for Fibre-rigidity of Standard Indian Cottons, 1927–1928 (150 Tests).

Table VII shows the observed frequency-distribution of the 4,000 tests, and the corresponding calculated values for the Type I_J curve, and also the frequency-distributions of the four sets of the successive 1,000 tests.

Table VII
Frequency-distributions of Fibre-rigidity

Class	4,000 Tests			Sets of 1,000 Tests				
	Observed	Type I_J	Deviation	First 1,000	Second 1,000	Third 1,000	Fourth 1,000	Type I_J
·0–·0044	1080	1043	37	235	382	205	258	261
·0045–·0084	467	505	38	111	123	89	144	126
·0085–·0124	317	368	51	99	86	55	77	92
·0125–·0164	264	290	26	94	46	61	63	72
·0165–·0204	233	238	5	84	32	62	55	59
·0205–·0244	187	199	12	50	42	51	44	50
·0245–·0284	163	170	7	46	36	43	38	42
·0285–·0324	152	147	5	46	32	44	30	37
·0325–·0364	129	127	2	37	23	34	35	32
·0365–·0404	126	111	15	36	24	47	19	28
·0405–·0444	106	97	9	26	20	30	30	24
·0445–·0484	87	85	2	19	21	27	20	21
·0485–·0524	82	75	7	18	16	33	15	19
·0525–·0564	71	66	5	14	12	21	24	16
·0565–·0604	68	58	10	14	10	30	14	14
·0605–·0644	58	51	7	9	9	27	13	13
·0645–·0684	59	45	14	8	11	21	19	11
·0685–·0724	48	40	8	10	13	11	14	10
·0725–·0764	39	35	4	8	6	12	13	9
·0765–·0804	38	31	7	2	10	17	9	8
·0805–·0844	34	28	6	8	3	11	12	7
·0845–·0884	23	25	2	4	5	9	5	6
·0885–·0924	23	22	1	1	3	13	6	5
·0925–·0964	23	19	4	6	4	4	9	5
·0965–·1004	16	17	1	3	2	6	5	4
·1005–·1044	12	15	3	2	5	3	2	4
·1045–·1084	12	13	1	2	2	5	3	3
·1085–·1124	6	12	6	1	0	2	3	3
·1125–·1164	10	10	0	0	3	5	2	2
·1165–·1204	7	9	2	0	2	3	2	2
·1205–·1244	8	8	0	1	2	3	2	2
·1245–·1284	7	7	0	0	1	3	3	2
·1285–·1324	6	6	0	1	0	3	2	1
·1325–·1364	4	6	2	1	0	2	1	1
·1365–·1404	3	5	2	0	1	2	0	1
·1405–·1444	7	4	3	0	5	2	0	1
·1445–·1484	5	4	1	0	1	1	3	1
·1485–·1524	3	3	0	1	2	0	0	1
·1525–·1564	0	3	3	0	0	0	0	1
·1565–·1604	3	2	1	0	2	1	0	0
above ·1604	14	12	2	3	3	2	6	3

The percentage difference between the observed and calculated frequencies is 7·7—a difference which is negligible—showing that the theoretical frequency-curve is an excellent fit of the observations.

The standard Indian cottons when tested year by year have for the most part also given extremely asymmetrical frequency-distributions. But as the number of tests is only 150 in each case it is not surprising that occasionally the skewness appears to be less. Fig. 7 shows the extent of the divergence in the frequency-distribution of the standard cottons of 1927–28, four samples being selected to show the range of the divergence. It will be observed that all the curves except that of Aligarh A.19 are extremely asymmetrical. Table VIII shows the frequency-constants for the fibre-rigidities

Table VIII

Frequency-constants for Fibre-rigidity of some of the Standard Indian Cottons, 1927-28 (150 Tests in each Case)

Cotton	Mean	Median	Mode	Standard Deviation	Skewness	Upper Quartile Q_3	Lower Quartile Q_1	Distance of Q_3 from Mean	Distance of Q_1 from Mean	Quartile Deviation	Coefficient of Asymmetry
	10^{-2} dyne-cm^2	10^{-2} dyne-cm^2	10^{-2} dyne-cm^2	10^{-2} dyne-cm^2		10^{-2} dyne-cm^2	10^{-2} dyne-cm^2	10^{-2} dyne-cm^2	10^{-2} dyne-cm^2	10^{-2} dyne-cm^2	
Surat 1027 A L.F. ...	2·425	1·493	—	2·452	—	3·823	0·486	1·398	1·939	1·669	0·223
P.A. 4F	3·798	2·355	—	3·912	—	5·331	0·932	1·533	2·866	2·200	0·351
C.A.9	3·040	2·825	2·395	1·749	0·369	4·013	1·774	0·973	1·266	1·120	0·096
Aligarh A.19 ...	7·950	7·089	5·367	5·345	0·483	10·606	4·413	2·656	3·537	3·097	0·111

of the four cottons in question. The frequency-curves of Surat 1027 A.L.F. and Punjab-American 4F are so skew as to approximate to the J-shape, for which no accurate modal values can be given, thus making it impossible to calculate the skewness from the ordinary formula; for this reason, another measure of asymmetry has been used in this table, viz. the coefficient of asymmetry, of which an explanation is given in the Appendix (page T356).

From the results given in Table VIII it is clear that 4F has the most skew distribution, Surat 1027 A.L.F. coming next, both giving much more skew curves than either C.A.9 or A.19, though the curves of these also are decidedly skew.

From an examination of the frequency-distributions of the other standard cottons of the same season, the following classification can be made—

Similar to 1027, A.L.F.—Wagad 4, Wagad 8.
,, P.A. 4F—285F, 289F, Dharwar 1, Gadag 1, Karunganni.
,, C.A.9—Cambodia Co. 1, Nandyal 14, Hagari 25, Umri Bani.
,, Aligarh A.19—Cawnpore K.22, Mollisoni, J.N.1.

The extreme asymmetry of the fibre-rigidity curves is no doubt due to the same causes as are responsible for the skewness of the fibre-strength curves. It is evident that as the rigidity of the fibre depends upon the square of the area of cross-section, the observed fibre-rigidity will be largely dependent upon the existence of thin places in the fibre; and the effect of such thin places will be exaggerated out of all proportion to their frequency and extent.

CONCLUSIONS

From the tables and curves given in the preceding pages, and from the evaluation of certain statistical indices given in the Appendix, it is concluded that the various frequency-curves for the different fibre-properties may be classified as follows—

1—Fibre-length } Moderately symmetrical and nearly normal.
2—Convolutions }
3—Fibre-width: Symmetrical—practically normal.
4—Fibre-strength: Moderately asymmetrical.
5—Fibre-rigidity: Extremely asymmetrical.

APPENDIX

Statistical Terms and Methods used in Curve-fitting, with Examples of their Application to Fibre-properties

I—INTRODUCTION

One great object of statistical methods is the description of a mass of observations in such terms as to make their significance more readily apprehended. If the observation-values exhibit large differences among themselves, we may without serious error treat as alike values which differ only very slightly from one another; we may therefore divide the range between the lowest and highest values into a convenient number of intervals (*class-intervals*), and then separate all the observations into groups according as they fall in one or other of the class-intervals, and treat as alike all the values in any one group. Thus, if we take 1,000 values of fibre-strength ranging from 0 to 14 grams, we may separate them into neighbouring groups as follows—

Those falling in the class-interval 0 to 0·9,
,, ,, ,, 1·0 to 1·9,
,, ,, ,, 2·0 to 2·9,

and so on. We may now count the number in each group, disregarding their actual values, and so obtain a table showing the *frequency of distribution* of the values, as under—

Table IX

Class-intervals	Frequency
0·0– 0·9	38
1·0– 1·9	165
2·0– 2·9	188
3·0– 3·9	159
4·0– 4·9	137
5·0– 5·9	114
6·0– 6·9	81
7·0– 7·9	48
8·0– 8·9	29
9·0– 9·9	19
10·0–10·9	15
11·0–11·9	6
12·0–12·9	0
13·0–13·9	1
14·0–14·9	0

A table, such as Table IX, showing the *frequency-distribution* of the observation-values is called a *frequency-table.* The choice of the class-interval is a matter of some importance; and is evidently related to the degree of variation; the class-interval should be sufficiently small to permit of all the observations within it being regarded as identical for practical purposes, and yet not so small that every class-interval contains but few values. In general, it is desirable to cover the whole range of the observations in about 20 class-intervals; it is usual also to make all the class-intervals of equal magnitude.

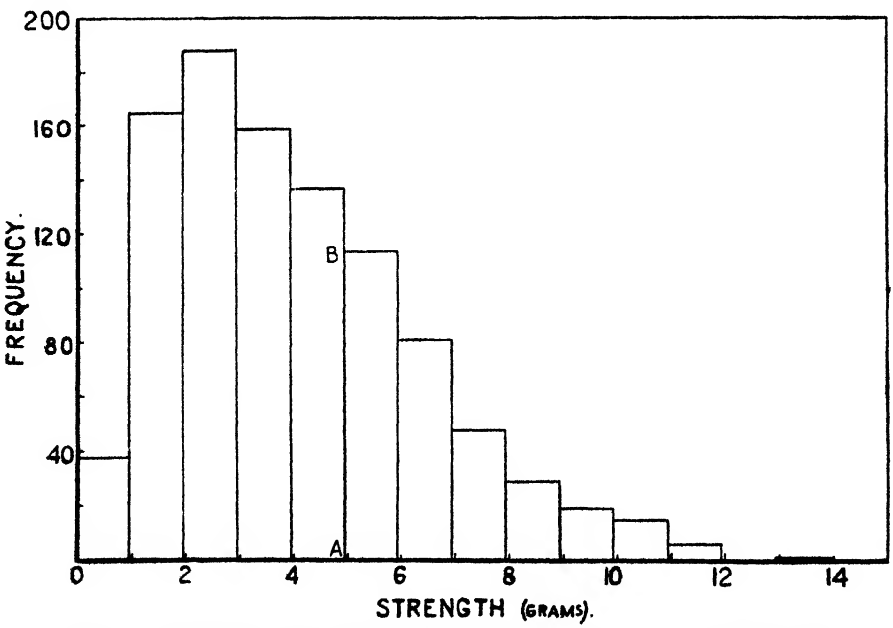

Fig. 8. Histogram for Fibre-strength of Surat 1027 A.L.F. (1,000 Tests).

The form of the frequency-distribution may often be more readily apprehended if it is expressed diagrammatically. (It should be remembered, however, that all statisticians are agreed that diagrams of themselves

prove nothing; diagrams may be useful for suggesting the form of a thesis, yet whenever it is sought to establish the thesis from a series of observations the final court of appeal must be certain well-established mathematical tests of the numerical results themselves.) One simple diagrammatic method of showing the frequency-distribution is by means of a *Histogram*. To draw the histogram, all we have to do is to construct for each class-interval a column of which the height is proportional to the corresponding frequency. When this is done for each class-interval, we obtain a number of rectangles, of equal base but varying altitude, placed side by side. Such a histogram, for the values of fibre-strength already given above, is shown in Fig. 8. The histogram allows us to see readily the general trend of the variation; furthermore, we see at once in which class-interval the maximum frequency occurs. The whole area of the histogram represents the total number of observations; moreover, the total area of the histogram to the left of the left-hand vertical side of any rectangle represents the total number of observations having a value equal to or less than the lower limit of the class-interval indicated by the said vertical side; and the total area to the right of the said vertical represents the total number of observations having a value greater than the lower limit of the class-interval in question; e.g. in Fig. 8, the area to the left of AB represents the total number of observations having a value equal to or less than 4·9 grams, and the area to the right of AB represents the total number of observations having a value greater than 4·9 grams.

Although the histogram is the most accurate method of graphically representing a frequency-distribution, yet for comparative purposes an extremely useful form of frequency-diagram is the *frequency-polygon*; this is constructed by joining the tops of ordinates erected at the mid-points of the rectangles representing the class-frequencies. As the number of tests made on any material is limited, and the material itself is usually merely a sample of the bulk, the frequency-polygon is generally irregular, and the class-frequencies are subject to considerable sampling fluctuation. If the class-interval could be made indefinitely small, and at the same time the number of observations were so increased that the class-frequencies ran smoothly, the frequency-polygon would merge into a continuous curve, known as a *frequency-curve*. Just as the whole area of a histogram represents the total number of observations, so may the whole area included between the frequency-curve and the X-axis; similarly, if an ordinate be drawn at any particular value n, the area to the left of this ordinate represents the total number of observations having a value less than n, and the area to the right of the ordinate represents the total number of observations having a value greater than n.

In actual fact, however, the observations cannot be increased indefinitely, so that the frequency-polygon does not become a continuous curve, and moreover, it usually contains certain irregularities. At the same time, there can be but little doubt that the distribution of the observation-values is such that they tend to give a frequency-curve. Hence the continuous curve which can be drawn so as to give the "best fit" to the observed frequency-distribution is taken to be the *theoretical frequency-curve* which the frequency-polygon tends to approach as the number of observations is increased. The method of determining the theoretical frequency-curve is described in Section III (page T357).

Frequency-curves are of many types. A very important type both in theory and practice is what is known as the *normal probability curve*, or sometimes simply as the *normal curve*. It may be shown mathematically that if, when any one of a series of observations is taken at random, the chance of its being greater than the mean is equal to its chance of being less than the mean, then the frequency-distribution of the values is represented by the normal curve. The form of the normal curve is shown in Fig. 9; this curve is the geometrical representation of the equation

$$y = \frac{N}{\sigma.\sqrt{2\pi}} \cdot e^{-\frac{x^2}{2\sigma^2}}$$

where y is the ordinate representing the frequency of occurence of a given value, x, the abscissa, expressed as a deviation from the mean; N is the total number of observations; σ is the standard deviation (page T352); π and e are constants having their usual mathematical significations, viz.—

$$\pi = 3{\cdot}14159\ldots\ldots$$
$$e = 2{\cdot}718\ \ \ldots\ldots$$

Actually Fig. 9 represents the frequency-distribution of 1,000 values of the fibre-width of Surat 1027 A.L.F.

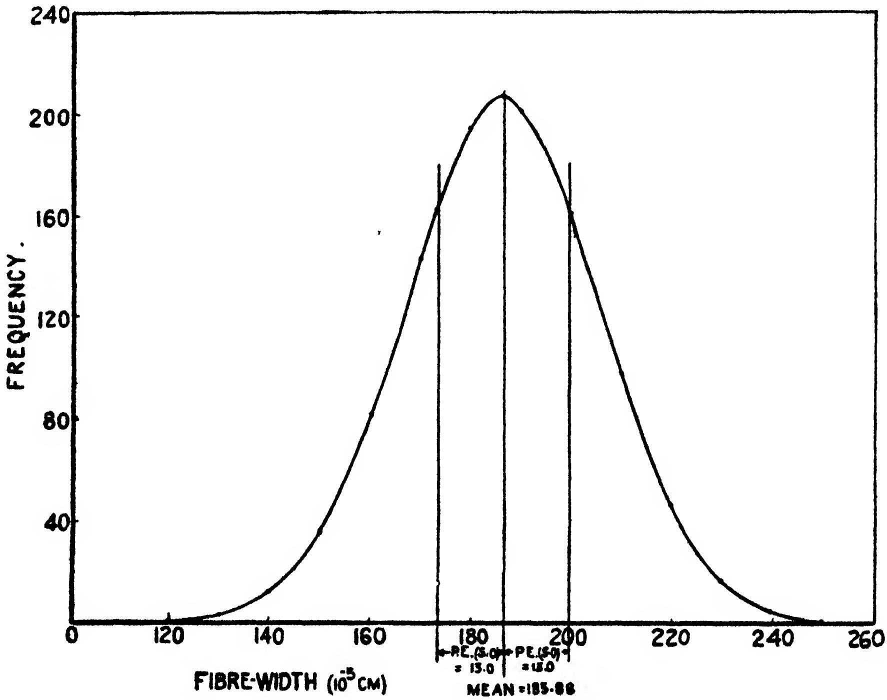

FIG. 9. Theoretical Frequency-curve for Fibre-width of Surat 1027 A.L.F. (1,000 Tests).

There are many cases, however, in which the chance that a randomly-selected value will be greater than the mean is not equal to its chance of being less than the mean, and in such cases the frequency-curve, instead of being of the normal type, is of a skew type. One type of skew curve is shown in

Fig. 10, which represents the frequency-distribution of 1,000 values of fibre-strength of Surat 1027 A.L.F. The values are indicated in Fig. 10 of certain important statistical quantities whose significance is explained in detail later, viz. mean (p. T350), median (p. T350), mode (p. T350), and quartiles, Q_1 and Q_3 (p. T353).

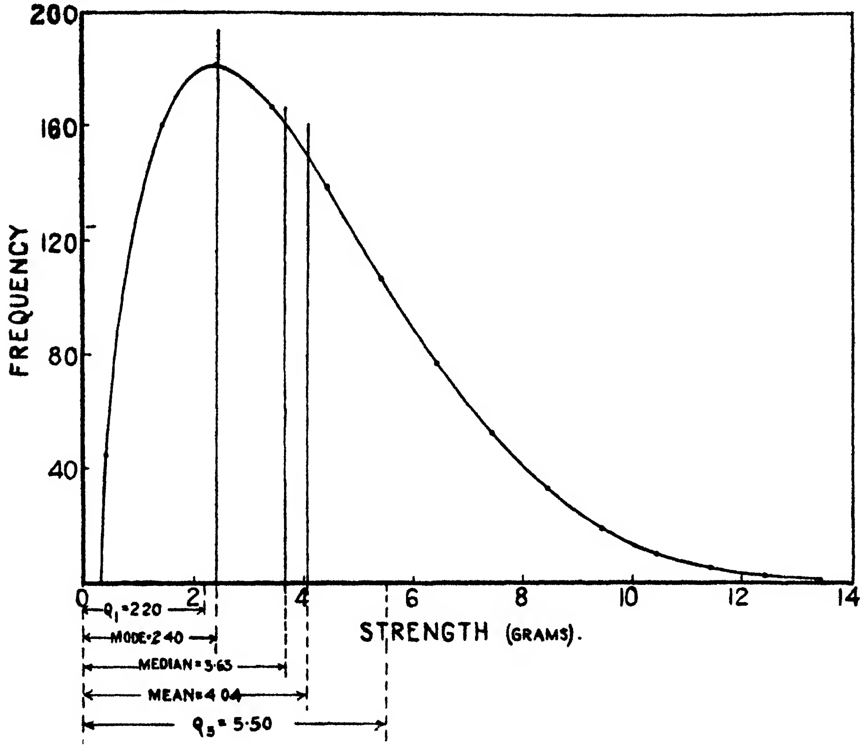

FIG. 10. Theoretical Frequency-curve for Fibre-strength of Surat 1027 A.L.F. (1,000 Tests).

The remainder of this Appendix is devoted to an account of certain statistical terms, and the application of statistical methods to a large series of observations with a view to determining the form of their distribution. It is divided into the following two sections—

II—An explanation of statistical terms used in curve-fitting.

III—Methods of curve-fitting.

II—STATISTICAL TERMS

The commonly-used statistical terms may conveniently be classified as—(*a*) averages, or measures of central tendencies; (*b*) measures of variability; (*c*) measures of the form of the frequency-curve, i.e. of skewness, and kurtosis*; and (*d*) measures of goodness of fit of a theoretical frequency-curve to observed values.

(*a*) *Averages, or Central Tendencies*—The average is a single number or point on a scale which is as far as possible the most representative of the series; it lies somewhere in the central part of the range of the series. There are three such measures commonly used in the case of frequency-distributions, viz. the arithmetic mean, the median, and the mode.

* See page T356.

The *arithmetic mean* is usually known as "the average" of all the observations, and is calculated by adding all the values and dividing their total by the *number* of values. It is the most probable value of the unknown, if the distribution of the observations strictly follows the normal law. The method of calculating this average from the frequency-table is given on page T359 *et seq.*

The *median* is the middle one of the observations when they are arranged in order of magnitude; evidently, seeing that for the frequency-curve the values are arranged in order of magnitude, and that the area between the frequency-curve and the X-axis represents the total number of observations, the median is that value of x at which the ordinate divides this whole area into two equal parts. In a symmetrical distribution the mean and the median must obviously coincide. When the values are arranged in a frequency-table, the median can be calculated from either of the following formulæ[12]—

$$\text{Median} = v + \frac{\frac{N}{2} - F}{f} i \quad \text{(Median calculated from lower values upward);}$$

$$\text{Median} = v' - \frac{\frac{N}{2} - F'}{f} i \quad \text{(Median calculated from higher values downward)}$$

where N = total number of observations;

f = frequency of class in which the measure $\frac{N \text{ I}}{2}$ lies;

i = class-interval of the median class;

F = sum of the frequencies of all classes below the median class;

F' = sum of the frequencies of all classes above the median class;

v = lower boundary of median class;

v' = upper boundary of median class.

The *mode* is practically the value of the observation which occurs most frequently; it is therefore the x-value at which the frequency-curve is at its highest point. The individual frequencies arising from random sampling are subject to error, so that the experimental mode, i.e. the mid-point of the class-interval having the highest frequency, may not coincide exactly with the true mode, which may be taken as the x-value at the maximum of the *theoretical* frequency-curve. The mode is an important measure in the case of skew curves.

The value of the mode can be calculated from the equation to the theoretical frequency-curve; and as different types of curve have different equations, so also do they have different formulæ for the calculation of the mode; however, Pearson has derived a general formula for the difference (D) between the mean and the mode, and from this formula, knowing the value of the mean, we can calculate that of the mode. The formula[13] is—

$$D = \frac{\sigma . \sqrt{\beta_1}\,(\beta_2 + 3)}{2(5\beta_2 - 6\beta_1 - 9)}$$

In this formula σ is the standard deviation (page T351); the definitions of β_1 and β_2 are given on page T359.

A simpler though only approximate alternative formula[14] for calculating the value of the mode is—

$$\text{Mode} = \text{Mean} - 3 \times (\text{Mean} - \text{Median}).$$

This formula has been used for the calculation of the mode in Tables VI and VIII.

In the case of the normal curve, the arithmetic mean, median, and mode are identical; hence when there exist any differences between them, these must be attributed to departure of the frequency-distribution from symmetry and normality.

The following Table X shows the values of the different averages for the several fibre-properties—

Table X

Constants Defining the Centre of Variation

	Mean M	Median Mdn	Mode M_0	Mean—Mode D	$\frac{\text{Mean—Mode}}{\text{Mean}} \times 100$
Fibre-strength (gram)	3·91	3·50	2·255	1·655	42·33
Fibre-rigidity (dyne-cm.^{2})	0·0247	0·146	—	—	—
Fibre-length (cm.) ...	2·33	2·35	2·38	−0·053	−2·27
Fibre-width (10^{-5} cm.)	179·88	179·64	178·80	1·08	0·60
Convolutions (total number per fibre)	88·78	87·51	83·83	4·95	5·57

(*b*) *Measures of Variability*—A measure of variability shows how far the observations are scattered on either side of the average. We shall consider three such measures, viz. range, standard deviation, and quartile deviation, and certain related measures.

Range—The range is simply the difference between the greatest and the least values of a variable; it is the simplest but worst of all measures of dispersion. Its great defect is that it depends solely on the extreme values, and therefore exaggerates their importance, leaving us still in ignorance of the distribution of the intermediate ones.

This difficulty has been surmounted, however, by Tippett,[15] who has recently succeeded in bringing the measure into the field of usefulness by using the *mean range*. For this purpose the observation-values are divided into columns of 10, 20, or 30, etc., and the highest and the lowest values in each column are marked. The difference between the *mean* maximum and *mean* minimum gives the value of the mean range for the sample. In Table X of *Biometrika*, Vol. XVII, pp. 386–387, Tippett gives the values of mean range of samples of different size taken from the normal population, the mean range being given in terms of the standard deviation of the original population; hence the standard deviation can be found by taking samples of a certain size, determining the mean range, and then dividing this by the constant given in the Table X as appropriate to that size of sample. The constants by which the mean range is divided in order to obtain the value of standard deviation for columns of 10, 20, and 40 values respectively, are 3·07751, 3·73495, and 4·32156. Tippett remarks that the method is rapid, although subject to larger sampling errors than the method of moments (page T358).

Although Tippett's method is strictly applicable only to cases of normal distribution, it may also be applied to distributions which are not far from normal. The following table (XI) shows the extent of the agreement of

Tippett's method of mean range with the method of moments when applied to the values of standard deviation for the fibre-properties of length, width, convolutions, and strength.

Table XI

Standard Deviations of Fibre-properties calculated by the Methods of Moments and Mean Range

No. of Test	Fibre-property	Standard Deviation	
		Method of Moments	Method of Mean Range (Groups of 20)
4,000	Fibre-length (cm)	0·491	0·4217
3,000	Fibre-width (10^{-5} cm.)	19·92	18·07
3,000	Convolutions	30·90	27·18
3,000	Strength (gram)	2·357	2·102

Standard Deviation—The standard deviation is a measure of dispersion which is based on all the observations. If the deviations are measured from the mean, then the square of the standard deviation is the average value of the square of a deviation. The standard deviation is usually represented by the symbol σ.

An example of the method of calculating σ from the frequency-table is included in the example on page T359 *et seq.*

As deviations are usually expressed in the same units as the observation-values themselves, so are the mean and the standard deviation; the standard deviation can however be expressed as a percentage of the arithmetic mean, and it is then termed the *coefficient of variation* (Pearson), which is a very useful measure of variability because it is independent of any unit of measurement.

It may be noted that the standard deviation, apart from its being a measure of dispersion, has a special significance in the case of a normal distribution, for it is the abscissa of the point of inflexion of the curve, i.e., the point where the curve changes its curvature towards the centre from concave to convex. The *probable error of a single observation* is merely a fractional part of the standard deviation (and$=0{\cdot}6745\ \sigma$); strictly speaking, it relates only to a normal curve, for which it has the following meaning—if ordinates be erected on either side of the mean at a distance equal to the probable error of a single observation, then each such ordinate will divide into two equal parts the half of the curve lying on that side of the mean. Hence it follows that if M is the mean and e the probable error of a single observation, one quarter of the observations have values less than $(M-e)$, and one quarter have values greater than $(M+e)$; or, taking both limits together, one half of the observations have values lying between $(M-e)$ and $(M+e)$, and the other half have values lying outside these limits.

The *probable error of the mean* of a normal distribution is related in a simple manner to the probable error of a single observation, and if n is the number of observations, the probable error of the mean is $\pm\frac{e}{\sqrt{n}}$. It signifies that if a large number of determinations of the mean of n observations be made, a quarter of them will be less than $M-\frac{e}{\sqrt{n}}$ and a quarter of them greater than $M+\frac{e}{\sqrt{n}}$.

It should be noted that although the probable error is a statistic which should properly only be used in connection with a normal distribution, it is often used for distributions which are not normal; in such cases it loses its special significance, and should not be regarded as signifying any more than a certain fraction of the standard deviation.

Quartile Deviation—If all the results are ranged in increasing order of magnitude, then the lower quartile Q_1 is defined as being that value of the variable such that one quarter of all the values observed are less than Q_1 and three-quarters greater. Similarly, the upper quartile Q_3 is defined as being that value of the variable such that three-quarters of all the values observed are less than Q_3, and one quarter greater. Thus half the values lie between Q_3 and Q_1, and half outside these limits. The quartile deviation Q.D., or *semi-interquartile range*, is denoted by Q and is defined as—$Q=\frac{Q_3-Q_1}{2}$. The quartile deviation, unlike the probable error, is a measure of dispersion which is independent of the form of the frequency-curve. The natural average with which to associate the quartile deviation is the median, for this is the central quartile and is defined, as we have already seen, by one half (i.e. two-quarters) of the values being below it and one half above it. It should be noted that the two quartiles are only at equal distances from the median in the case of curves which are symmetrical about the ordinate through the median.

The following table shows the values of different measures of variability for the several fibre-properties—

Table XII

Constants Measuring Dispersion or Degree of Variation

	Standard Deviation	Coefficient of Variation	Probable Error (Single Observation) P.E (s.o.)	P.E (s.o.) × 100 ÷ Mean	Irregularity (%)
Fibre-length (cm.)	0·491	21·0	0·33	14·2	17·0
Fibre-width (10^{-5} cm.) ...	19·92	11·05	13·41	7·4	8·8
Convolutions ...	30·90	34·8	20·84	23·5	28·3
Fibre-strength (gram)	2·357	60·4	1·59	40·7	40·8
Fibre-rigidity (10^{-3} dyne-cm^2)	2·936	118·8	19·8	80·2	69·2

From the last two columns it can easily be seen that both dispersion and irregularity are greatest in fibre-rigidity and least in fibre-width.

Application of Measures of Variability

The measures of variability often help us to decide whether a difference between two quantities is a real difference or whether it is merely a consequence of random sampling. Thus it has been stated that the frequency-distributions of fibre-length, fibre-width, and convolutions are practically of a normal type, although the observed frequency-distributions do not coincide exactly with the theoretical ones. Are these differences real, or have they arisen simply because a small sample taken from even a normal population is likely to show some departure from normality? To test the point we can use the probable error. On the assumption that errors of random sampling are distributed strictly in accordance with the normal law, it is

customary to regard a result or difference as significant if it exceeds three times its probable error. This is purely conventional, however, and Pearl has suggested taking four times the probable error as the index of significance.[16] The chief point to remember is that these indices expressed in terms of the probable error accept as significant certain odds that the event in question is due to errors of random sampling. For three times the probable error, the odds are 1 in 23 that the difference is due to errors of random sampling; for four times the probable error the corresponding odds are 1 in 143. Hence in the latter case a difference is only accepted as significant and not due to random sampling if the odds in favour of it are more than 142 to 1.

Example—The following table shows the values of the mean, median (mean—mode), and the skewness (discussed later, page T355), together with their probable errors calculated as for a normal distribution, for the properties of fibre-length, fibre-width, and number of convolutions.

Table XIII

	No. of Tests	Mean M	Median Mdn	Mean—Mode D	Skewness
Fibre-length (cm.)	4,000	$2{\cdot}33 \pm {\cdot}005$	$2{\cdot}35 \pm {\cdot}0066$	$0{\cdot}05 \pm {\cdot}008$	$0{\cdot}1076 \pm {\cdot}0163$
Fibre-width (10^{-5} cm.) ...	3,000	$179{\cdot}88 \pm {\cdot}422$	$179{\cdot}64 \pm {\cdot}532$	$1{\cdot}08 \pm {\cdot}299$	$0{\cdot}054 \pm {\cdot}0150$
Convolutions ...	3,000	$88{\cdot}78 \pm {\cdot}670$	$87{\cdot}51 \pm {\cdot}84$	$4{\cdot}95 \pm {\cdot}466$	$0{\cdot}1602 \pm {\cdot}0150$

The probable errors have been calculated from the following formulæ,[17] in which σ=standard deviation, and n=number of observations—

$$\text{P.E. of mean} = {\cdot}67449\frac{\sigma}{\sqrt{n}}$$

$$\text{P.E. of median} = 1{\cdot}253 \times \text{P.E. of mean}$$

$$\text{P.E. of skewness} = {\cdot}67449\sqrt{\frac{3}{2n}}$$

$$\text{P.E. of (mean—mode)} = \sigma \times \text{P.E. of skewness}$$

From this table we may draw the following conclusions—

(*a*) *Fibre-length*—The difference between mean and median is about 2½ times its probable error, and is therefore not significant; the difference between mean and mode is about six times its probable error, and is therefore significant; the value of skewness is also about six times its probable error, so that the distribution must be regarded as skew, though its departure from symmetry is very small.

(*b*) *Fibre-width*—The difference between the mean and median is only about one-third of its probable error, and is not significant; the difference between the mean and mode, and also the skewness, are each about three times their respective probable errors, and hence are doubtfully significant; we finally conclude, therefore, that, as the skewness is very small, the fibre-width distribution is nearly symmetrical within the errors of random sampling.

(*c*) *Convolutions*—The difference between the mean and median is less than 1½ times its probable error; on the other hand, the difference between the mean and mode, and also the skewness, are each more than ten times their respective probable errors; hence, the results for skewness must be

regarded as real and not due to errors of random sampling, and the frequency-curve is definitely skew. However, the departure from normality is not very great, as shown on page T333.

(*d*) *Measures of the Form of the Frequency-curve: skewness and kurtosis*—If a series of observations is not symmetrically distributed about some average, we need some method of expressing the extent of the departure from symmetry. Actually a number of methods have been proposed for the purpose. One simple and common method takes advantage of the fact that, for a perfectly symmetrical frequency-curve, the mean, median, and mode all coincide, and the more the distribution departs from symmetry, the further apart do these three values become, the difference between the mean and mode being greatest. This difference is therefore used as a measure of skewness, but in order to secure an index for comparative purposes, the absolute difference between the mean and the mode is divided by the standard deviation of the given distribution.

$$\text{i.e. Skewness } (S_k) = \frac{\text{mean—mode}}{\text{standard deviation}}$$

A difficulty arises, however, that usually we cannot fix the position of the mode with any degree of accuracy unless we know the theoretical frequency-curve; in these circumstances the value of the mode may be calculated by one of the formulæ given on page T351.

Various other measures of skewness have been suggested, and as these are based on different considerations they naturally lead to different numerical values for the skewness. Thus, Charlier has proposed a formula based on the generalised system of frequency-curves which he has developed from a series originally proposed by Gram, and which is a method of moments substantially different from Pearson's (see page T357 *et seq*). His formula[18] is $S_k = -3a_3$ where a_3 is a coefficient in the Gram-Charlier series, Type A. It can be shown that this formula is equivalent to $S_k = -3a_3 = \frac{\mu_3}{2\sigma^3}$ (The meaning of μ_3 is given on page T359, line 8.

Bowley[19] has suggested a measure of skewness based on quartiles—

$$S_k = \frac{q_2 - q_1}{q_2 + q_1}$$

where q_2 and q_1 are respectively the distances of the upper and lower quartiles from the median. But as the value of the median is not affected by the magnitude of extreme deviations from the average, this formula does not adequately represent the skewness contributed by the tails of the frequency-curve.

Another measure based on quartiles may be developed from the following considerations—We have already seen that the interquartile range, i.e. the distance between the upper quartile and the lower quartile, is exactly equal to twice the probable error of a single observation in normal distributions; but whereas the interquartile range has the same significance for skew as for normal distributions, i.e. it always contains just one half the values, this is not true of the range between the probable errors. Hence if the distances of the lower and upper quartiles from the *mean* be represented by ε_1 and ε_2 respectively, we have, for a normal distribution only—

$$\varepsilon_1 = \varepsilon_2 = Q = \text{P.E. (s.o.)},$$
$$\varepsilon_1 - \varepsilon_2 = 0.$$

But where the distribution is not symmetrical, $\varepsilon_1-\varepsilon_2$ will not be zero; moreover, its arithmetical value will increase as the asymmetry increases, so that we may use the value $\varepsilon_1-\varepsilon_2$, relative to the mean, M, as a measure of skewness; we may call $\frac{\varepsilon_1-\varepsilon_2}{M}$ *the coefficient of asymmetry*. The skewness is positive or negative according as ε_1 is greater or less than ε_2.

The use of this coefficient of asymmetry may be illustrated by the following table, giving the values of Q_3, Q_1, Q, and P.E. (s.o.), and of ε_1, ε_2, and $\frac{\varepsilon_1-\varepsilon_2}{M}$ for the different fibre-properties—

Table XIV

Coefficients of Asymmetry

	Mean	Q_3	Q_1	ε_1	ε_2	Q	P.E (s.o.)	$\frac{\varepsilon_1-\varepsilon_2}{M}$
Fibre-length (cm.)	2·33	2·677	1·987	0·343	0·347	0·345	0·331	−·017
Fibre-width (10^{-5} cm.) ...	179·88	192·8	166·4	13·48	12·94	13·20	13·41	+·0029
Convolutions per fibre ...	88·78	110·44	64·81	23·97	21·66	22·81	20·84	+·026
Fibre-strength (gram) ...	3·91	5·26	2·10	1·81	1·35	1·58	1·59	+·118
Fibre-rigidity (dyne-cm²) ...	0·0247	0·0368	0·0042	0·0205	0·0118	0·0163	0·0199	+·340

From this table it is clear that the value of $\frac{\varepsilon_1-\varepsilon_2}{M}$ is greatest for fibre-rigidity, fairly high for fibre-strength, small for fibre-length and convolutions, and practically negligible for fibre-width. In the case of fibre-strength it is interesting to note that the values of Q and P.E. are almost identical (1·58 and 1·59 respectively), from which one might conclude that the distribution is normal; but on closer examination it is found that ε_1 and ε_2 are different, and that the value of $\frac{\varepsilon_1-\varepsilon_2}{M}$ is ·118. Hence it follows that the equality of Q and P.E. is not a sufficient indication that the distribution is normal, but must be supplemented by the further condition that ε_1, ε_2, Q, and P.E. are all equal to one another.

Kurtosis—This is a measure of the relative degree of flatness of a frequency-curve in the region about its mode, as compared with the normal curve. The normal curve is *mesokurtic*; a curve is *platykurtic* if it is more flat-topped than the normal, and *leptokurtic*, if it is more peaked. If k is a measure of kurtosis,[16a] then $k=\beta_2-3$.

The following table shows for the different fibre-properties the values of skewness and kurtosis obtained from Pearson's formulæ, and of β_1, β_2, and $\varkappa_2$ which are certain functions of the moments actually used for classifying the curves—

Table XV

Constants Defining the Shape of the Frequency-curve

	β_1	β_2	Skewness	Kurtosis	Criterion $\varkappa_2 = \dfrac{\beta_1(\beta_2+3)^2}{4(4\beta_2-3\beta_1)(2\beta_2-3\beta_1-6)}$
Fibre-length ...	0·036	2·880	−0·1076	−0·12	−0·0787
Fibre-width ...	0·0146	3·2064	+0·0540	+0·2064	+0·0299
Convolutions ...	0·1119	3·236	+0·1602	+0·236	+0·6333
Fibre-strength	1·2112	4·4161	+0·7020	+1·4161	−1·46
Fibre-rigidity	4·6984	9·1434	+1·5440	+6·1434	−4·26

(*e*) *Goodness of Fit*—The consideration of measures of goodness of fit is deferred to page T366, after a description of the methods used in curve-fitting.

III—METHODS OF CURVE-FITTING

As stated on page T347, although in practice our observations lead us to a frequency-polygon, and not to a frequency-curve, yet there can be but little doubt that if the observations were sufficiently numerous they would actually give a frequency-curve. The question arises, therefore, what is the frequency-curve which the observations tend to give? We may distinguish four parts in the answer to this question—

(1) The determination of the type of equation which best represents the frequency-distribution; this type-equation will contain certain constants.

(2) The determination of the particular arithmetical values of the constants in the type-equation which are appropriate to the given set of observations; in this way we obtain the equation of the ideal frequency-curve to which the frequency-polygon approximates; and this frequency-curve may be regarded as representing approximately the frequency-distribution of the whole bulk or total population of which the particular case investigated is a sample.

(3) The determination of the theoretical frequencies by calculation from the equation to the theoretical frequency-curve found in (2).

(4) The determination of the degree of agreement between the theoretical distribution, as deduced from (2), with the actual distribution; this is commonly known as the determination of the "goodness of fit."

(a) The Selection of the Type-equation

The first proceeding is to find the equation which gives in a general way the desired shape of curve; now this may be a matter of trial and experience. The determination of the constants in the equation, when found, may be carried out in a number of different ways. Pearson, however, has devised a certain scheme of classification of frequency-curves having very wide applicability, and in connection with this scheme has provided certain criteria, the evaluation of which makes possible the assignment of a given frequency-distribution to one of his types. Pearson's method is known as the "method of moments," which we now proceed to explain and illustrate by reference to 1,000 tests of fibre-strength of Surat 1027 A.L.F. As we shall see later, the method of moments not only allows us to determine the type of frequency-curve but also to calculate the appropriate values of the various constants. The method of moments has been used throughout the present paper for determining the curves of closest fit.

The Method of Moments—Let us consider a frequency-curve which, with the x-axis and the extreme ordinates, includes an area of unity. If the number of class-intervals is indefinitely increased, the area of the frequency-curve included in any one class-interval will be indefinitely decreased; such an indefinitely small area is known as an "elementary area." Now let us suppose that the whole area of the frequency-curve is divided up into elementary areas; then if each elementary area is multiplied by *its distance* from the y-axis (drawn through some arbitary origin), and all the products are added together, their sum is the *first moment* of the curve about the y-axis. If instead of multiplying each elementary area by its distance from the y axis, we multiply it by the *square* of its distance from the y-axis, and add, the resulting sum is the *second moment* of the curve; if we multiply each elementary area by the *cube of its distance* from the y-axis and add, the resulting sum is the *third moment* of the curve. Similarly, according as we multiply each elementary area by the fourth, fifth, sixth, etc., powers of its distance from the y-axis, on adding the products we obtain the fourth, fifth, sixth, etc., moments of the curve.

When dealing with an empirical curve, however, we do not have available the elementary areas resulting from an indefinitely large number of class-intervals, and consequently we use instead the areas included in the actual class-intervals; moreover, the empirical curve will represent a total of say N observations; if n is the number of observations included in any one class-interval, then the fraction of the whole area represented by the class-interval is $\frac{n}{N}$. The distance of the class-interval from the y-axis may be taken as the distance of its mid-ordinate. Hence if ν_1' represents the first moment of the empirical curve about the y-axis, ν_2' the second moment, and so on, we have—

$$\nu_1' = \Sigma\frac{n}{N}x = \frac{1}{N}\Sigma(nx)$$

$$\nu_2' = \Sigma\frac{n}{N}x^2 = \frac{1}{N}\Sigma(nx^2)$$

$$\nu_3' = \Sigma\frac{n}{N}x^3 = \frac{1}{N}\Sigma(nx^3)$$

$$\nu_4' = \Sigma\frac{n}{N}x^4 = \frac{1}{N}\Sigma(nx^4)$$

We often desire to know the values of the moments about the mean, and if we represent the first, second, third, and fourth moments by ν_1, ν_2, ν_3, ν_4 respectively, and d represents the distance between the mean and the y-axis, it can be shown[11a] that

$$d = \nu_1' = \frac{1}{N}\Sigma(nx)$$

$$\nu_2 = \nu_2' - d^2$$

$$\nu_3 = \nu_3' - 3d\nu_2 - d^3$$

$$\nu_4 = \nu_4' - 4d\nu_3 - 6d^2\nu_2 - d^4$$

It is not strictly correct, however, to assume that each class-frequency is concentrated at the mid-point of the class, and certain corrections—known as Sheppard's corrections, from their discoverer—have to be applied to

correct for this error of grouping; the corrections are only applicable in the case of curves which have high contact at both ends, i.e. when the frequency-curve tapers off gradually in both directions. If the correct second, third, and fourth moments about the mean are represented by μ_2, μ_3, μ_4, and if h represents the class-interval expressed in the same units as the average, we have

$$\mu_2 = \nu_2 - \frac{1}{12}h^2$$

$$\mu_3 = \nu_3$$

$$\mu_4 = \nu_4 - \frac{1}{2}h^2\nu_2 + \frac{7}{240}h^4$$

As previously mentioned, it is by reference to these moments that a curve of closest fit is obtained for an empirical frequency-curve. What has to be done is to select a theoretical curve such that its moments are the same as the moments of the empirical curve.

Pearson has shown that certain functions of these moments can actually be used as a method of classifying frequency-curves, and he has accordingly defined a number of types of curve according to their values of these functions. The functions in question are β_1 and β_2, which are defined in terms of the moments as follows—

$$\beta_1 = \frac{\mu_3^2}{\mu_2^3}$$

$$\beta_2 = \frac{\mu_4}{\mu_2^2}$$

When β_1 and β_2 have been evaluated, the required type of the frequency curve is ascertained from a chart in which curves are described in the $\beta_1\beta_2$ plane, given in "Tables for Statisticians and Biometricians."[13a]. Where these "Tables for Statisticians" are not available, a function of β_1 and β_2, known as "the criterion," $\varkappa_2$, can be used to determine the type of the frequency-curve; the value of $\varkappa_2$ is given by

$$\varkappa_2 = \frac{\beta_1(\beta_2+3)^2}{4(4\beta_2-3\beta_1)(2\beta_2-3\beta_1-6)}$$

The three constants, β_1, β_2, and $\varkappa_2$, are therefore of fundamental importance in determining the type of the curve to which a given series of measurements belong. In the normal curve $\beta_1=0$, $\beta_2=3$, $\varkappa_2=0$. If $\varkappa_2$ is negative, the frequency-curve is of Type I; if $\varkappa_2$ is positive and less than unity, the frequency curve is of Type IV; and if $\varkappa_2$ is greater than unity, the frequency-curve is of Type VI.

Example—As an example of the application of the method of moments, we give below, in detail, the necessary calculations for the determination of the type of frequency-distribution in the case of the fibre-strength of Surat 1027 A.L.F., 1925–26.

First a frequency-table is computed, as under, to show the frequency m of each class, the deviation from an arbitrary origin, and the values of mv, mv^2, mv^3, and mv^4.

Table XVI

The Calculation of Moments for the Frequency-distribution of the Fibre-strength of Surat 1027 A.L.F., 1925-26

1	2	3	4	5	6	7
Strength-class grams	Deviation from Arbitrary Mean in Class Units (v)	Frequency (m)	mv	mv^2	mv^3	mv^4
0– 0·9	−4	38	−152	608	−2,432	9,728
1·0– 1·9	−3	165	−495	1,485	−4,455	13,365
2·0– 2·9	−2	188	−376	752	−1,504	3,008
3·0– 3·9	−1	159	−159	159	− 159	159
4·0– 4·9	0	137	0	0	0	0
5·0– 5·9	1	114	114	114	114	114
6·0– 6·9	2	81	162	324	648	1,296
7·0– 7·9	3	48	144	432	1,296	3,888
8·0– 8·9	4	29	116	464	1,856	7,424
9·0– 9·9	5	19	95	475	2,375	11,875
10·0–10·9	6	15	90	540	3,240	19,440
11·0–11·9	7	6	42	294	2,058	14,406
12·0–12·9	8	0	0	0	0	0
13·0–13·9	9	1	9	81	729	6,561
	Totals ...	1,000	−410	5,728	3,766	91,264

Column 1 gives the class-intervals of the frequency-distribution. For the purpose of calculation, the arbitrary mean is taken as 4·45, being the mid-point of group 4·0–4·9; the moments are calculated with reference to this point as origin. Column 2 shows the deviations from the arbitrary origin, in class-units, of the strength-values given in column 1; thus the mid-point of group 1·0–1·9 is 1·45; its deviation from the arbitrary mean 4·45 is 1·45 4·45= −3, as shown in column 2, line 2.

Column 3 shows the frequency of occurrence, m, of fibres having a strength between the limits of each class-interval in column 1. Thus the figure 165 (column 3, line 2) indicates that, out of 1,000 fibres, 165 have a strength falling between the limits 1·0 and 1·9 grams.

Column 4 shows the values of products of m (column 3) and v (column 2) and serves for the calculation of the first moment.

Columns 5, 6, and 7 show the values of mv^2, mv^3, and mv^4, and serve for the determination of the second, third, and fourth moments. They are obtained by successively multiplying the figures in column 2 by the corresponding figures in columns 4, 5, and 6 respectively.

At the bottom of the table are given the algebraic sums of the figures in the respective columns. If ν_1', ν_2', ν_3' and ν_4' represent the first four moments respectively, we have

$$\nu_1'=\frac{\Sigma(mv)}{N}= -0{\cdot}410$$

$$\nu_2'=\frac{\Sigma(mv^2)}{N}=5{\cdot}7280$$

$$\nu_3'=\frac{\Sigma(mv^3)}{N}=3{\cdot}7660$$

$$\nu_4'=\frac{\Sigma(mv^4)}{N}=91{\cdot}2640$$

where N=the total number of tests=1,000.

From these moments about an arbitrary origin, we may now calculate the second, third, and fourth moments (ν_2, ν_3, and ν_4) *about the mean.* We have—

$\nu_2=5{\cdot}728-({\cdot}41)^2=5{\cdot}728-{\cdot}1681=5{\cdot}5599$

$\nu_3=3{\cdot}764-3\times{\cdot}41\times5{\cdot}5599-(-{\cdot}41)^3=10{\cdot}6619$

$\nu_4=91{\cdot}256-4\times{\cdot}41\times10{\cdot}6619-6\times{\cdot}1681\times5{\cdot}5599-(-{\cdot}41)^4=103{\cdot}11237$

In this case Sheppard's corrections are not applied because the frequency-curve does *not* have high contact at both ends.

Now d is the distance in class-units of the arbitrary mean from the real mean, so that the real mean=(arbitrary mean$+d$), and therefore the mean value=$4{\cdot}45+(-{\cdot}410)=4{\cdot}04$ grams.

If σ denotes the standard deviation,

$$\sigma=\sqrt{\nu_2}=2{\cdot}357944$$

Hence, two very important statistical measures (mean value and standard deviation) are easily obtained from the moments.

When the moments have been obtained, the next step is to calculate the two simple functions of them, indicated by β_1 and β_2; here we have to use the uncorrected moments (ν) instead of the corrected moments (μ)—

$$\beta_1=\frac{\nu_3^{\,2}}{\nu_2^{\,3}}=\frac{(10{\cdot}6619)^2}{(5{\cdot}5599)^3}={\cdot}661406$$

$$\beta_2=\frac{\nu_4}{\nu_2^{\,2}}=\frac{103{\cdot}11237}{(5{\cdot}5599)^2}=3{\cdot}33562$$

From β_1 and β_2, two other constants represented by $\varkappa_1$ and $\varkappa_2$ are calculated—

$$\varkappa_1=2\beta_2-3\beta_1-6=-1{\cdot}312978$$

$$\varkappa_2=\frac{\beta_1(\beta_2+3)^2}{4(4\beta_2-3\beta_1)\,(2\beta_2-3\beta_1-6)}=-{\cdot}4206$$

$\varkappa_1$ and $\varkappa_2$ are generally called the *criteria,* for they are used in fixing the type of the curve.

If $\varkappa_1$=0 or is very small, Type III is applicable ($2\beta_2=3\beta_1+6$).

If $\varkappa_2=0$, the Normal curve is applicable ($\beta_1=0$, $\beta_2=3$), or Type II ($\beta_1=0$, $\beta_2<3$), or Type VII ($\beta_1=0$, $\beta_2>3$).

If $\varkappa_2$ is negative, Type I is applicable.

If $\varkappa_2$ is positive but >0 and <1, Type IV is applicable.

In the present example $\varkappa_2$ is negative, so that Type I is applicable. The general type equation of Type I is—

$$y=y_0\left(1+\frac{x}{l_1}\right)^{m_1}\left(1-\frac{x}{l_2}\right)^{m_2}$$

(b) The Calculations of the Constants of the Type I Equation

$$y=y_0\left(1+\frac{x}{l_1}\right)^{m_1}\left(1-\frac{x}{l_2}\right)^{m_2}$$

In this equation y represents the frequency corresponding to a given value of x. The origin of the curve is at the mode—so that x here represents the deviation of the original values *from the mode.*

y_0=the modal frequency or the ordinate at the mode.

l_1 and l_2 represent the range of the curve on the two sides of the mode.

Hence, in order to calculate the theoretical frequencies from this equation, we must first determine the position of the mode, and the arithmetical values of y_0, l_1, l_2, m_1, and m_2. These can be obtained from the moments and moment-functions already determined, in the following manner.

To simplify the expressions we introduce a constant, r, given by

$$r=6(\beta_2-\beta_1-1)\div(6+3\beta_1-2\beta_2)=7{\cdot}650765$$

The skewness, α, is given by[20]

$$\alpha=\tfrac{1}{2}\sqrt{\beta_1}\left(\frac{r+2}{r-2}\right)=0{\cdot}6944780$$

The distance, D, between the mean and the mode is given by

$$D=\alpha\sigma=1{\cdot}63754$$

$$\therefore\quad Dr=1{\cdot}63754\times7{\cdot}65=12{\cdot}52843$$

The two physical constants, l_1 and l_2, can now be determined in terms of σ, β_1, D, and r.

If l is the total range $(=l_1+l_2)$ we have

$$l=\frac{\sigma}{2}\sqrt{\beta_1(r+2)^2+16(r+1)}=16{\cdot}67375$$

$$l_1=\tfrac{1}{2}(l-Dr)=2{\cdot}07266$$

$$l_2=l-l_1=14{\cdot}60109$$

The two algebraic constants m_1 and m_2 are determined from the following relations—

$$m_1=\frac{l_1}{l}(r-2)=0{\cdot}7024318$$

$$m_2=(r-2)-m_1=4{\cdot}948333$$

The modal frequency y_0 can now be determined from the equation—

$$y_0=\frac{N}{l_1+l_2}\cdot\frac{m_1^{m_1}\times m_2^{m_2}}{(m_1+m_2)^{m_1+m_2}}\cdot\frac{\Gamma(m_1+m_2+2)}{\Gamma(m_1+1)\,\Gamma(m_2+1)}$$

$$=\frac{1000}{16{\cdot}67375}\times\frac{{\cdot}7024318^{\cdot7024318}\times4{\cdot}948333^{4\cdot948333}}{5{\cdot}650765^{5\cdot650765}}\times\frac{\Gamma(7{\cdot}650765)}{\Gamma(1{\cdot}7024318)\Gamma(5{\cdot}948333)}$$

$$=181{\cdot}275$$

Substituting the values of the various constants in the equation we have

$$y=181{\cdot}275\left(1-\frac{x}{2{\cdot}07266}\right)^{0\cdot7024318}\times\left(1-\frac{x}{14{\cdot}60109}\right)^{4\cdot948333}$$

(c) The Determination of the Theoretical Frequencies

Having obtained the equation to the theoretical curve of closest fit, we desire to ascertain from it the theoretical frequencies of the various class-intervals; when these have been obtained we may actually construct the theoretical frequency-curve by plotting them as ordinates at the mid-points of the corresponding class-intervals. There are two general methods of determining the theoretical frequencies, viz.—

(i) *The Method of Ordinates*—In this method the value of x is calculated as from the mid-point of each class-interval, and the values of y as calculated from the equation give us the corresponding theoretical frequencies.

Table XVII

Theoretical Frequencies for the Fibre-properties of Length, Width, Convolutions, and Strength

Length (last 3,000 tests)			Fibre-width (3,000 Tests)			Convolutions (3,000 Tests)			Strength (3,000 Tests)		
Class-interval	Theoretical Frequency by Method of		Class-interval	Theoretical Frequency by Method of		Class-interval	Theoretical Frequency by Method of		Class-interval	Theoretical Frequency by Method of	
	Areas	Ordinates		Areas	Ordinates		Areas	Ordinates		Areas	Ordinates
0·35–0·65	1·9	1·5	94·5–104·5	0·2	0·2	14·5– 29·5	58·4	56·2	0– 0·95	127·3	127·3
0·65–0·95	11·6	10·1	104·5–114·5	1·3	1·2	29·5– 44·5	145·3	148·6	0·95– 1·95	516·8	531·5
0·95–1·25	51·0	47·9	114·5–124·5	6·6	6·1	44·5– 59·5	287·1	285·8	1·95– 2·95	590·9	596·5
1·25–1·55	167·5	164·4	124·5–134·5	25·9	24·5	59·5– 74·5	450·6	453·0	2·95– 3·95	520·5	522·1
1·55–1·85	384·6	386·0	134·5–144·5	79·3	77·0	74·5– 89·5	561·3	566·9	3·95– 4·95	407·3	407·2
1·85–2·15	621·7	630·1	144·5–154·5	190·1	187·8	89·5–104·5	555·3	561·0	4·95– 5·95	295·0	295·6
2·15–2·45	707·3	716·1	154·5–164·5	355·8	356·0	104·5–119·5	436·2	427·9	5·95– 6·95	202·2	202·8
2·45–2·75	566·1	568·0	164·5–174·5	520·3	524·4	119·5–134·5	272·1	270·3	6·95– 7·95	133·6	132·9
2·75–3·05	319·0	314·7	174·5–184·5	594·3	600·8	134·5–149·5	134·8	131·8	7·95– 8·95	83·4	82·9
3·05–3·35	126·3	120·6	184·5–194·5	530·7	534·7	149·5–164·5	53·0	50·7	8·95– 9·95	52·0	50·5
3·35–3·65	35·2	32·3	194·5–204·5	370·1	369·9	164·5–179·5	16·5	15·4	9·95–10·95	31·3	29·4
3·65–3·95	6·9	6·1	204·5–214·5	201·7	198·9	179·5–194·5	4·1	3·8	10·95–11·95	17·6	16·4
above 3·95	1·1	0·8	214·5–224·5	85·8	83·1	194·5–209·5	0·9	0·7	11·95–12·95	9·5	8·8
			224·5–234·5	28·5	26·5	above 209·5	0·2	0·1	12·95–13·95	4·9	4·5
			234·5–244·5	7·7	6·8				13·95–14·95	2·4	2·2
			244·5–254·5	1·5	1·3				14·95–15·95	1·1	1·0
			above 254·5	0·3	0·2						

(ii) *The Method of Areas*—In this method we determine the areas of the strips between the ordinates at the beginning and end of each class-interval, as bounded by the curve and the x-axis; these areas represent the frequencies of the corresponding class-intervals, and can be determined by the application of Simpson's rule or other quadrature formula, but the best method is to determine them from a Table of the Probability Integral if this is available for the particular type of curve.

The theoretical frequencies given in Tables I, II, III, IV, and VII have been calculated by the method of ordinates, except for the first class-interval both of Tables IV and VII, for which it has been necessary to use the method of areas, because of the steepness of the curve in this class-interval. In the case of Tables I to IV the requisite calculations have also been made by the method of areas, and the results obtained so nearly resemble those of the alternative method, that the theoretical frequency-curves, Figs. 1–4, equally well represent either set of frequency-values. Table XVII shows the frequency-values actually obtained by the two methods; for the properties of length, width, and convolutions the areas have been calculated as if the frequency-curve for each were normal, i.e. by means of the tables of the Probability Integral for the normal curve[13a]; for the fibre-strength the areas have been calculated by means of Simpson's rule.

A tabular arrangement of the steps in the calculation of the theoretical frequencies by the method of ordinates [11b] is given in Table XVIII.

Column 1 gives the values of strength, in class-intervals of 1 gram, for which the theoretical frequencies are required.

Column 2 gives the values of $\left(1+\frac{x}{l_1}\right)$

For the first class-interval 0–0·9—

$$x=0{\cdot}45-2{\cdot}40246\ (=\text{Mode})=-1{\cdot}95246$$

$$\frac{1}{l_1}=\frac{1}{2{\cdot}07266}=0{\cdot}4824718$$

$$\therefore\ \left(1+\frac{x}{l_1}\right)=1+{\cdot}4824718\times-1{\cdot}95246={\cdot}0579932$$

The values of $\left(1+\frac{x}{l_1}\right)$ for successive class-intervals are obtained by adding the constant difference, $\frac{1}{l_1}={\cdot}4824718$, to the value for the preceding class-interval.

Column 3 gives the values of $\left(1-\frac{x}{l_2}\right)$. For the first class-interval

$$\frac{1}{l_2}=\frac{1}{14{\cdot}60109}={\cdot}06848803$$

$$\left(1-\frac{x}{l_2}\right)=1-{\cdot}06848803\times-1{\cdot}95246=1{\cdot}13371700$$

The values of $\left(1-\frac{x}{l_2}\right)$ for the successive class-intervals are obtained by subtracting the constant difference, $\frac{1}{l_2}={\cdot}06848803$, from the value for the preceding class-interval.

Table XVIII

Calculation of Theoretical Frequencies from the Equation $y=y_0\left(1+\frac{x}{l_1}\right)^{m_1}\left(1-\frac{x}{l_2}\right)^{m_2}$

1	2	3	4	5	6	7	8	9	10
Strength-class grams	$\left(1+\frac{x}{l_1}\right)$	$\left(1-\frac{x}{l_2}\right)$	$\log\left(1+\frac{x}{l_1}\right)$	$\log\left(1-\frac{x}{l_2}\right)$	$m_1\times$ Col 4	$m_2\times$ Col. 5	Col. 6 + Col. 7 + $\log y_0=\log y_x$	Theoretical Frequency (y_x)	Observed Frequency
0– 0·9	0·0579932	1·13371700	$\bar{2}$·7633772	0·0535046	$\bar{1}$·1311544	0·264759	1·6532401	45·0028	38
1·0– 1·9	0·5404650	1·06522897	$\bar{1}$·7327677	0·0274430	$\bar{1}$·8122850	0·135797	2·2054096	160·4758	165
2·0– 2·9	1·0229368	0·99674094	0·0098493	$\bar{1}$·9985823	0·0069184	$\bar{1}$·992985	2·2572306	180·8133	188
3·0– 3·9	1·5054086	0·92825291	0·1776544	$\bar{1}$·9676664	0·1247894	$\bar{1}$·840002	2·2221186	166·7703	159
4·0– 4·9	1·9878804	0·85976488	0·2983903	$\bar{1}$·9343797	0·2095978	$\bar{1}$·675287	2·1422120	138·7433	137
5·0– 5·9	2·4703522	0·91276850	0·3927591	$\bar{1}$·9832850	0·2752505	$\bar{1}$·496894	2·0294717	107·0217	114
6·0– 6·9	2·9528240	0·72278882	0·4702375	$\bar{1}$·8580115	0·3303088	$\bar{1}$·297392	1·8850280	76·7411	81
7·0– 7·9	3·4352958	0·65430079	0·5359639	$\bar{1}$·8157775	0·3764762	$\bar{1}$·088405	1·7232191	52·8712	48
8·0– 8·9	3·9177676	0·58581276	0·5920386	$\bar{1}$·7677588	0·4158647	$\bar{2}$·859552	1·5327469	34·0993	29
9·0– 9·9	4·4002594	0·51732473	0·6434783	$\bar{1}$·7137633	0·4519974	$\bar{2}$·583585	1·2929096	19·6295	19
10·0–10·9	4·8827312	0·44883670	0·6886619	$\bar{1}$·6520884	0·4837358	$\bar{2}$·278417	1·0194800	10·4590	15
11·0–11·9	5·3652030	0·38034867	0·7295861	$\bar{1}$·5801817	0·5124820	$\bar{3}$·921599	0·6914082	4·9137	6
12·0–12·9	5·8476748	0·31186064	0·7669832	$\bar{1}$·4939607	0·5387504	$\bar{3}$·495947	0·2919746	1·9587	0
13·0–13·9	6·3301466	0·24337261	0·8014138	$\bar{1}$·3862715	0·5629360	$\bar{4}$·963067	$\bar{1}$·7833312	0·6072	1
14·0–14·9	6·8126184	0·17488458	0·8333131	$\bar{1}$·2427515	0·5834300	$\bar{4}$·252883	$\bar{1}$·0936402	0·1241	0
							Totals ...	1000·2310	1000·0

The value of y is computed by means of the logarithms of the several quantities on the right-hand side of the equation; hence arise columns 4, 5, 6, and 7. Column 8 gives the log of the theoretical frequency—

$$\log y = \log y_0 + m_1 \log\left(1+\frac{x}{l_1}\right) + m_2 \log\left(1-\frac{x}{l_2}\right)$$

In column 10 are given the values of the frequencies obtained by experiment.

(d) Measures of Goodness of Fit

When a theoretical curve is used to describe a set of observed facts, it is necessary to know how far the experimental results agree with the expected ones. By comparing the actual and theoretical curves we can obtain a general idea as to whether the agreement is close or not; but a method devised by Pearson tells us much more than this, for it indicates the degree of probability that the deviations between the theoretical and observed values will be due to random sampling. Pearson's method[21] is as follows—

Find the difference between the observed frequency m and the theoretical value m' for each class; divide the square of this difference in each case by the theoretical frequency; then the sum of the quotients is the index of the closeness of fit, and is designated χ^2; thus we have

$$\chi^2 = \Sigma \frac{(m-m')^2}{m'}$$

The square of the difference is used in order that both positive and negative differences may be utilised, while the ratio of the square of the difference to the theoretical frequency is required in order to take into account the size of the group. It is clear that the more closely the observed numbers agree with those expected, the smaller will χ^2 be. The values of P, the probability that a no better fit will be obtained in random sampling from the theoretical distribution, have been computed by Elderton for a considerable range of values of χ^2 and of n (=number of classes); Elderton's tables are given in Pearson's "Tables for Statisticians and Biometricians."[13e]. Knowing the number of classes* and the value of χ^2 for any frequency-distribution, we can ascertain the value of P from the tables, and if its value is greater than 0·1, it may be assumed that the hypothesis is established by experiment.[23]

From the method of evaluation of χ^2 it is clear that all the frequency-classes are taken into consideration, so that it is a measure of the combined discrepancies between the observed and computed frequencies. But sometimes it is found that although there is close agreement between the observed and expected numbers in most of the classes, yet the value of χ^2 is high (and the value of P consequently low), as a consequence of great discrepancy in one or two classes. In such a case it is essential, before finally discarding a hypothesis under consideration, to ascertain whether these large differences may be simply due to fluctuations arising in random sampling. This is done by calculating the quantity $\sigma_{,,}$ known as the standard error

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* As pointed out by R. A. Fisher,[22] it is necessary to use n' instead of n (the actual number of classes) when determining P from Elderton's tables, where n' is the value obtained by subtracting from n the number of moments employed in calculating the theoretical frequency-curve. For the normal curve, $n'=n-2$; for Type I, $n'=n-4$.

of sampling,[24] for each of the classes which exhibit the greatest differences. If the difference in question is not greater than $2\sigma_e$ we conclude that it may be due to sampling fluctuations.

As the assignment of the different frequency-distributions in this paper to their respective types has been tested in every case by applying the criteria of goodness of fit, two examples of the application of the method are given below. In the first example, dealing with fibre-strength, the agreement is very good and the conclusion simple; in the second example, dealing with fibre-width, abnormal discrepancies occur in two class-intervals and these are accordingly examined in the manner just described.

Example 1. *Fibre-strength*—Table XIX shows the frequency-distribution of 1,000 tests of fibre-strength on Surat 1027 A.L.F., 1926–27, and the values of m, m', and $(m-m')^2/m'$ for each class-interval, by means of which the value of χ^2 can be calculated.

Table XIX

Frequency-distribution of 1,000 Tests of Fibre-strength on Surat 1027 A.L.F., 1925-26

Mid-point of Class grams	Observed Frequency	Theoretical Frequency (Type I)	$m-m'$	$(m-m')^2$	$\frac{(m-m')^2}{m'}$
0·45	38	45	−7	49	1·09
1·45	165	160	−5	25	0·16
2·45	188	181	−7	49	0·27
3·45	159	167	−8	64	0·38
4·45	137	139	−2	4	0·03
5·45	114	107	−7	49	0·46
6·45	81	77	−4	16	0·21
7·45	48	53	−5	25	0·47
8·45	29	34	−5	25	0·74
9·45	19	19	0	0	0·00
10·45	15	10	−5	25	2·50
11·45	6	5	−1	1	0·20
12·45	0	2	−2	4	2·00
13·45	1	1	0	0	0·00

We see that the value of $\Sigma \frac{(m-m')^2}{m'}$ is 8·51; and from the tables of "Goodness of Fit" given in Pearson's "Tables for Statisticians and Biometricians"[134] we find the following values for P—

$$\chi^2=8, \quad n'=10 : P=\cdot 534146$$
$$\chi^2=9, \quad n'=10 : P=\cdot 437274$$
$$\therefore \text{ for } \chi^2=8\cdot 51, n'=10 : P=\cdot 48474$$

This value of P signifies that if the real distribution is of Type I, random sampling from the theoretical distribution would, in 48 out of 100 trials, give us a fit which is no better than that actually observed. Hence the fit must be considered to be a very good one.

Example 2. *Fibre-width*—The following table shows the frequency-distribution and values of m, m', and $\frac{(m-m')^2}{m'}$ for two separate 1,000 tests of fibre-width on Surat 1027 A.L.F., 1925–26.

Table XX

Calculation of "Goodness of Fit" for the Frequency-distribution of the Fibre-width of Surat 1027 A.L.F., 1925-26

Fibre-width 10^{-5} cm.	Second 1,000 Tests					Third 1,000 Tests				
	Observed frequency m	Theoretical frequency m'	$m-m'$	$(m-m')^2$	$\frac{(m-m')^2}{m'}$	Observed frequency m	Theoretical frequency m'	$m-m'$	$(m-m')^2$	$\frac{(m-m')^2}{m'}$
Below 124·5	1	0·7	0·3	0·09	0·13	1	2·2	− 1·2	1·44	0·65
124·5–134·5	3	3·1	− 0·1	0·01	0·00	4	7·6	− 3·6	12·96	1·70
134·5–144·5	15	12·1	2·9	8·41	0·70	17	25·0	− 8·0	64·00	2·56
144·5–154·5	32	35·6	− 3·6	12·96	0·36	65	59·3	5·7	32·49	0·55
154·5–164·5	81	81·3	− 0·3	0·09	0·00	132	116·0	16·0	256·00	2·17
164·5–174·5	127	142·7	−15·7	246·49	1·73	166	173·1	− 7·1	50·41	0·29
174·5–184·5	214	192·9	21·1	445·21	2·31	221	200·7	20·3	412·09	2·05
184·5–194·5	205	200·4	4·6	21·16	0·11	172	180·6	− 8·6	73·96	0·41
194·5–204·5	161	161·0	0·0	0·0	0·0	110	126·1	−16·1	259·21	2·05
204·5–214·5	89	99·4	−10·4	108·16	1·09	64	68·3	− 4·3	18·49	0·27
214·5–224·5	48	47·3	0·7	0·49	0·01	26	28·2	− 2·2	4·84	0·17
224·5–234·5	16	17·3	− 1·3	1·69	0·10	16	9·9	6·1	37·21	3·76
234·5–244·5	5	4·9	0·1	0·01	0·00	5	2·4	2·6	6·76	2·82
Above 244·5	3	1·3	1·7	2·89	2·22	1	0·6	0·4	0·16	0·27
Totals ...	1000	1000·0	—	—	8·76	1000	1000·0	—	—	19·72

From this table we deduce the following—

Second 1,000 *Tests*—χ^2=8·76, P=·6438 (n'=12), which shows that if the real distribution is described by the normal curve, random sampling from the theoretical distribution would, in 64 trials out of 100, give us a fit which is not better than that actually observed. Hence this fit is a very good one.

Third 1,000 *Tests*—χ^2=19·72, P=·04975 (n'=12). The value of χ^2 is very high and consequently the value of P is very low, and signifies that if the real distribution is described by the normal curve, random sampling from the theoretical distribution would, in 95 cases out of 100, give us a better fit than that actually observed. But if we examine the last column of the table above, we find that the classes 224·5–234·5 and 234·5–244·5 (both near the tail) contribute 3·76 and 2·82 units respectively, or nearly one-third the total, to the value of χ^2. In order to determine the significance of these particular differences, we evaluate the standard error of sampling for the classes where the difference between observation and theory is very marked. These values are given in the following table—

Table XXI

Class	Observed Frequency	Theoretical Frequency (normal)	Difference	Standard Error of Sampling	Difference in Terms of Standard Error of Sampling
124·5–134·5	4	7·6	− 3·6	2·75	−1·31
134·5–144·5	17	25·0	− 8·0	4·94	−1·62
154·5–164·5	132	116·0	+16·0	10·13	+1·58
174·5–184·5	220	200·7	+20·3	12·67	+1·60
194·5–204·5	110	126·1	−16·1	10·50	−1·53
224·5–234·5	16	9·9	+ 6·1	3·13	+1·95
234·5–244·5	5	2·4	+ 2·6	1·55	+1·68

The greatest discrepancies occur for the classes 224·5–234·5 and 234·5–244·5, for which the differences, expressed in terms of the standard error of sampling, are 1·95 and 1·68 respectively (column 6). Reference to the table of the Probability Integral shows that positive deviations as great as these are to be expected thrice and five times respectively out of 100 trials. Hence we conclude that even the greatest differences between observation and theory are not so large as to compel us to reject the normal curve in describing the distribution of fibre-width.

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TECHNOLOGICAL LABORATORY BOMBAY
16*th April* 1930

25—MEASUREMENT OF FALSE TWIST TUBE PERFORMANCE BY CINEMATOGRAPHIC METHODS

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ABSTRACT

The adaptation of a standard cine-camera for use on a worsted spinning frame is described, also the experimental routine of measurement of false twist. Figures and curves are given showing how false twist varies with the speed of the tube and the angle of entry of the roving, the most interesting feature being that increase of speed beyond a certain point has no further influence on the twist inserted.

INTRODUCTION

In applying false twist to worsted rovings* it was soon found that the twist inserted depended both on the speed of the tube and the angle at which the roving entered the tube. For easy observation of the twist a black and white marl roving of about the same weight and quality was sometimes run down to an adjoining spindle. From the appearance of this roving in the space between the middle rollers and the false twist tube a rough estimate could be formed of the vigour of action of the tube.

To analyse the action and to find the separate effects of angle and speed, also to investigate other factors which might influence the twist inserted, such rough observation was not good enough. Nor could information be gleaned from textbooks or journal articles. False twist is little mentioned in textile literature, and where it is mentioned the reference is vague and qualitative, without numerical data.

Measurements taken after the spinning frame has stopped are of no value, as the twist tends to run out as soon as the frame slows down. Though some twist remains, it cannot be taken as representing in any proportion the twist present at full speed. Nor is a single measurement of any value. The rovings used, like all textile materials and products, are far from uniform; their thickness and also, probably, their readiness to receive twist, vary along their length. It was obvious to the eye that the twist was changing from second to second, rendering a single measurement both difficult and valueless. Twenty observations, preferably more, are necessary to obtain a representative figure.

EXPERIMENTAL METHOD

The only practicable method of making these observations seemed to be by the analysis of a rapid succession of photographs of the roving. The frequency required—about one per second—was much lower than cinematograph frequency, yet too high for ordinary photography. The development, too, of such a large number of plates or films would absorb an excessive amount of time.

Some time previously a beginning had been made in the investigation of certain processes of carding and spinning by the cinematograph, employing an expert operator. But such expert assistance had its obvious disadvantages, and for successful and extended work it was essential that the Association's own staff should acquire the necessary technique. The problem at present under discussion, requiring a speed and amount of film about one-sixteenth of that required for normal cinematography, offered a good

* W.I.R.A. Private Publications—No. 61, pp. 10, 13; No. 82, pp. 69, 70, 73. J. Text Inst., 1927, 18, T377–T383.

training ground in the technique of lighting, exposure, camera fixing, development, etc. The camera selected was a hand-operated Cine-Kodak and it has proved a more adaptable instrument than a spring-operated model would have been.

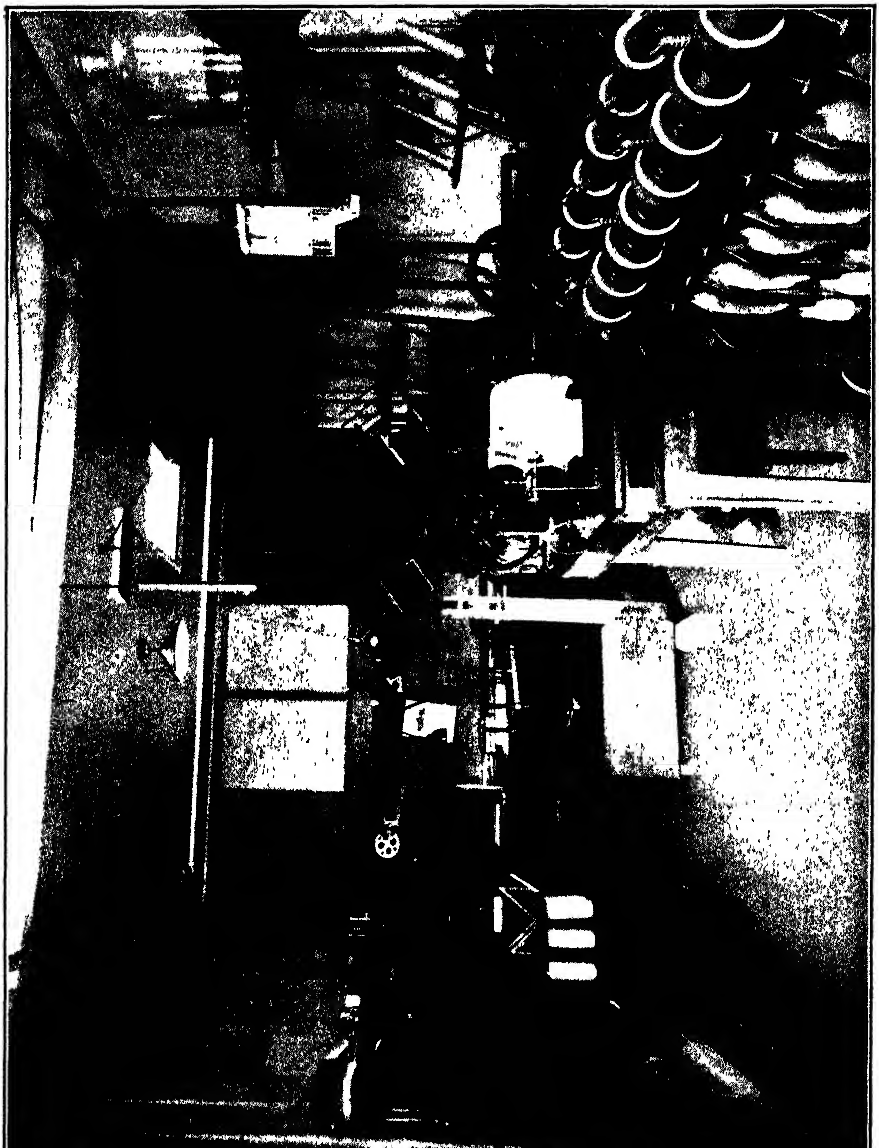
The instrument is of course intended for general photography at normal distances. To get a "close-up" of a few inches of roving a "magnifier" had to be attached to the lens and a stand made to enable the camera to overhang the spinning frame at a distance of about 12 in. from the roving. The standard gearing of the hand-driven Cine-Kodak gives eight pictures per turn of the crank, but an 8 to 1 reducing gear is supplied as a fitment. The crank of this fitment has a definite and easily felt stopping place. Each turn opens and closes the revolving shutter and moves the film on one step. But the exposure remains the same fraction of a cycle as at the higher speed and proved to be much too long for a vibrating roving. An adaptor was therefore made for the lens to carry a pocket-camera shutter and also the "magnifier" mentioned above. Lighting had to be intense and constant. For this an arc lamp (with condenser) was supported in such a way as to illuminate the false twist tube and the roving immediately above.

The camera can be seen almost in the centre of Fig. 1, set at an angle and pointing down at the drafting rollers of the far-away spinning frame. The base of the stand is a baulk of wood 12 in. × 12 in. × 24 in., forming a counterweight for the camera and a platform for the operator. The arc lamp is not shown.

With these arrangements excellent results were obtained. The Kodak Co. discourage private development of their cinema films, as they have special equipment and methods to ensure results of uniform density and to reverse the blacks and whites of the picture, giving a positive result without printing on to another film. For general observation where half-tone effects are desired (such as some tentative experiments which were made on the analysis of finger motion in piecing) we have found it well to take advantage of these facilities, but for work such as that being described, where tones and reversal are immaterial and exact measurement of one feature is required, we have had better results from our own development, probably because we concentrated on the parts of the picture to be measured. There was the further advantage of dealing immediately with the few feet of film used in each set of experiments.

For the inspection and measurement of each individual exposure, a single picture projector was built. It uses a more powerful lamp than the standard Kodak projector, passing the beam through a water bath to prevent damage to the film. The picture, instead of being projected on the usual screen, is given on a horizontal plane for easy application of scales, protractors, and other appliances, and the whole is enclosed by a box and curtains so that it can be used without the room being darkened. The size chosen for the picture was 12 in. × 10 in. A smaller picture required very precise measuring, while nothing was gained by a larger picture, the grain of the film being already easily visible at a size of 12 in. × 10 in. The positions of parts can be recorded by pencil lines for comparison with the next picture, and enlarged prints can of course be taken of any particular exposure. The projector can be seen in Fig. 1 at the left-hand end of the far-away table.

The routine of measurement was as follows—A sheet of paper was so manipulated on the plane of projection that the commencement of a turn



Fig

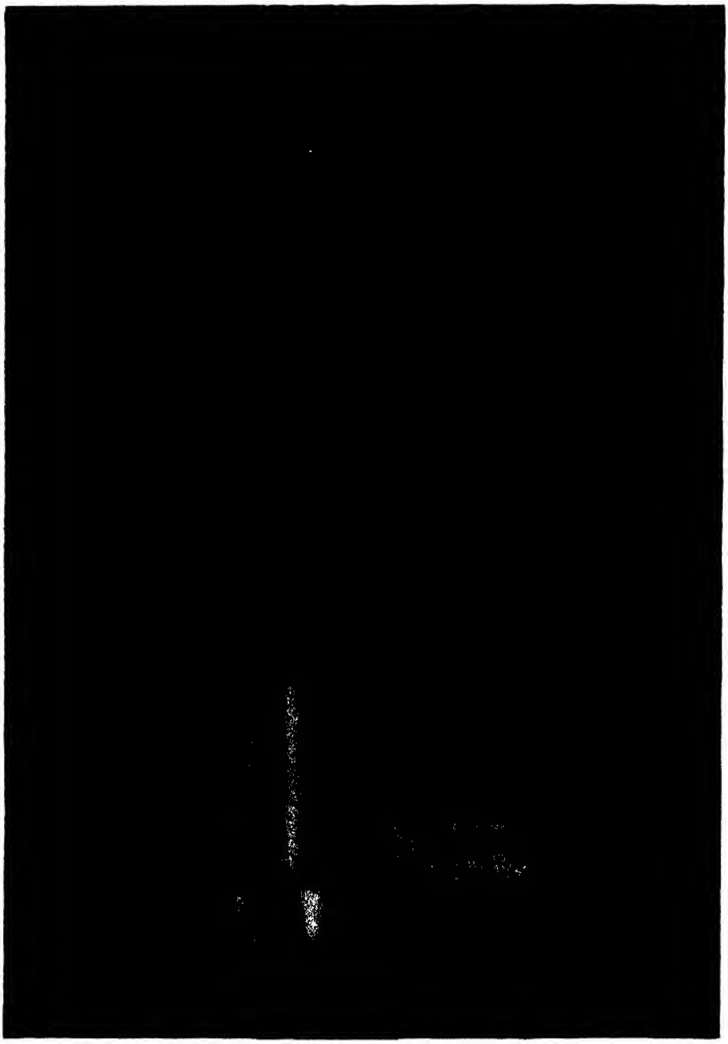


Fig. 2

coincided with a mark on a line on the paper, as shown in Fig. 2. Pencil marks were made at as many complete turns as appeared on that particular exposure. The film was then moved on, and the paper manipulated so that the mark last made coincided with the beginning of the first clear turn on the new exposure. In this way the total length of ten or twenty turns of twist were collected on one line, their length measured and divided by ten or twenty, giving projected inches per turn. Among the pictures taken was one of a steel rule held in the plane of the false twist tube, and from the projection of this a factor to convert projected inches per turn to actual turns per inch was calculated.

RESULTS

The table below gives a selection of the results obtained as the speed of the false twist tube and the angle of entry of the roving were varied. Each figure is a mean of 20-30 consecutive observations of twist. The speed of the remainder of the frame was constant, being that corresponding to a spindle speed of 6,000 r.p.m. The roving used was an 18-dram Botany, drafted about 6 in the first draft and 6 in the draft under observation. The passage through the false twist tube was square.

Speed of False Twist Tube r.p.m.	Angle of Entry to False Twist Tube							
	4°	9°	13°	18°	19½°	20°	23°	26°
	Twist in turns per inch							
51	0·58	0·61	0·63	..	...	0·78		..
80	0·82	0·84	0·88	0·78	0·75	0·86	0·91	0·95
120	0·94	1·06	1·23	1·19	1·22	1·24	1·31	0·95
138	0·96	1·18	1·33	1·22	1·28	1·27	1·33	1·38
160	1·06	1·23	1·34	1·34	1·38	1·54	1·47	1·51
190	1·10	1·25	1·41	1·50	1·48	1·57	1·52	1·59
225	1·28	1·33	1·53	1·56	1·56	1·69	1·75	1·86
265	1·15	1·35	1·52	1·56	1·65	1·75	1·73	1·95
300	1·29	1·43	1·60	1·71	1·83	1·94	1·88	2·06
750	1·41	1·85	2·15	1·96	2·13	1·50	2·35	2·58
1,200	1·49	1·78	2·16	2·14	2·31	2·54	2·61	2·65
1,800	1·30	1·85	2·14	2·30	2·53	2·37	2·66	3·07

It will be seen that the figures, though individually erratic, show distinct general trends. These trends are shown in the curves in Fig. 3, which have been drawn from the above figures and a few others, and subjected to a good deal of smoothing out.

CONCLUSIONS

The most important conclusion to be drawn from the table and curves is that there is always a definite maximum twist which can be inserted at a given angle of entry, and while the early stages of speed increase have considerable effect, the advantage gained by increased speed falls off until a point is attained beyond which further increase of speed has no effect on twist. There is in fact distinct evidence of a decrease as higher speeds are reached, an interesting fact for which a reason can be suggested. On the theoretical side these results link in with others which are being obtained on the behaviour of yarn tension devices. It is becoming clear that the usual "laws" of solid friction do not apply to the friction of wool on metal, or at least of worsted yarn on metal. What is more interesting is that the discrepancies have points in common with the practical man's "rule of thumb."

Further sets of experiments were carried out on the effect of the linear velocity of the roving on the twist inserted, also on the effect of the shape of the passage through the false twist tube, round, pentagonal, and hexagonal orifices being tried in addition to square, but the results from these experiments are neither complete enough or conclusive enough for publication.

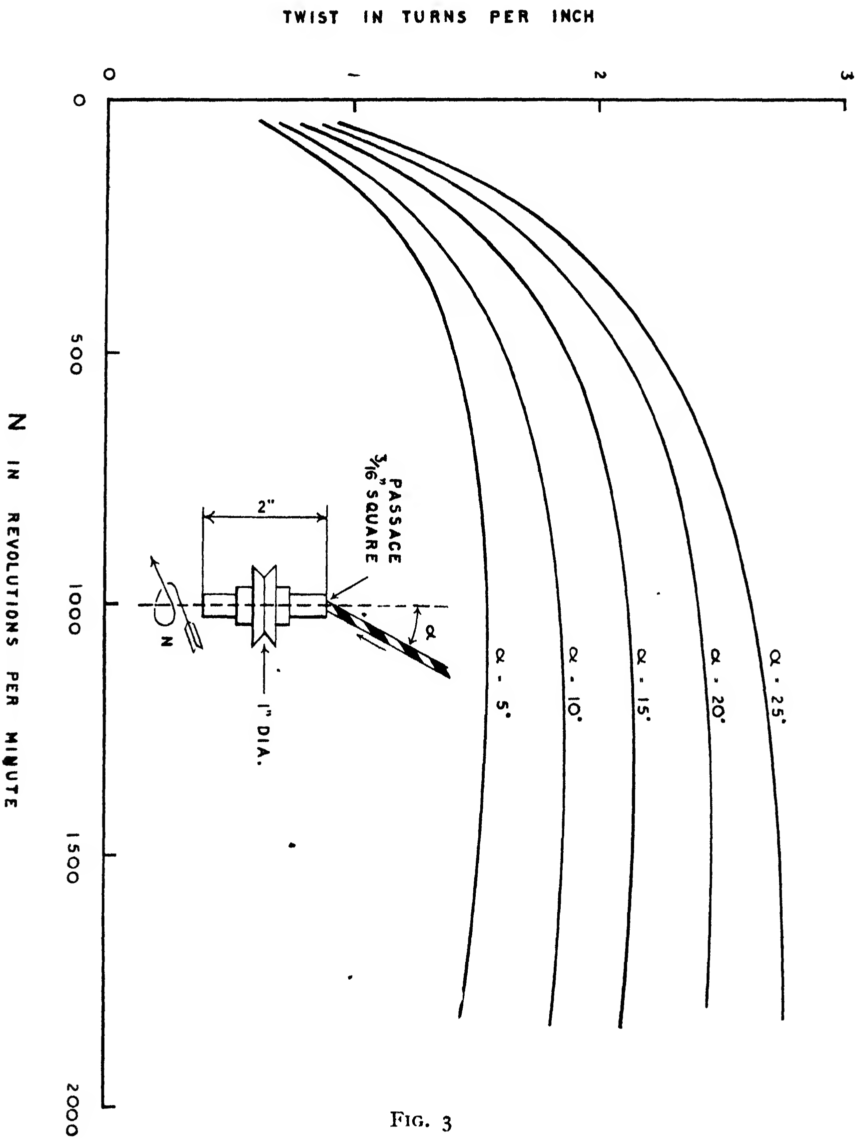


Fig. 3

The writer's thanks are due to his assistants, Messrs. S. Townend and J. R. Ickringill, for their enthusiasm in apparatus construction and to the latter for carrying out with accuracy the routine of photography and measurement.

THE JOURNAL OF THE TEXTILE INSTITUTE TRANSACTIONS

26—THE "HANDLE" OF CLOTH AS A MEASURABLE QUANTITY

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ABSTRACT

In judging the feel or "handle" of a material, use is made of such sensations as stiffness or limpness, hardness or softness, and roughness or smoothness. It is desirable to devise physical tests that analyse and reflect the sensations felt and assign numerical values to the measurements. The present paper describes tests that reflect the first groups of sensations, namely, stiffness and hardness, whilst the sensation that is experienced in stroking a material, obviously connected with frictional properties, will be dealt with in another paper.

An instrument is described on which it is possible to measure the angle through which a specimen of cloth droops when a definite length is held out over an edge. By means of a mathematical formula that is fully developed in an appendix to the paper this angle is converted into a term called the *bending length* of the material. This quantity may be defined as the length of fabric that will bend under its own weight to a definite extent. It is strictly a measure of the draping quality of a fabric. The stiffer the material, the longer is the "bending length."

From the "bending length" and the weight of the material, a simple calculation gives a quantity called the *flexural rigidity* which measures the resistance to bending or the stiffness that would be appreciated by the fingers. These two quantities should be measured both along the weft and along the warp in woven fabrics, but it is unnecessary to apply the test in any diagonal direction. The stiffness of the fabric as a whole is completely governed by the warp-way and weft-way stiffnesses, and these separate quantities may be converted into a single quantity for stiffness in any direction.

Another property that is sensed when a fabric is grasped is thickness, but this depends on the amount by which the material is squeezed, so that the sensation combines that of thickness and hardness. The measurement of thickness is discussed in detail, for it is not so simple as it might appear. Having standardised the method, however, it is easy to measure hardness by determining thickness under different pressures.

It is often desirable to compare the stiffness of materials of different thicknesses, for example, to compare a cloth before and after a process like calendering. For this purpose the above flexural rigidity may be converted into a quantity called the *bending modulus* that takes account of thickness. Flexural rigidity itself is highly dependent on thickness; in fact, doubling the thickness increases the flexural rigidity eightfold. The bending modulus on the other hand, is in a sense a measure of the intrinsic stiffness of the material. Generally speaking, it reflects the degree of compactness, or of the adhesion between fibres and threads—the difference between what is described as a "full" handle and "papery."

The standard procedure for determining bending length may be varied with regard to the shape and dimensions of the test specimen for very stiff or very limp materials, and the alternative calculations are demonstrated. A different but more laborious method for measuring flexural rigidity is also described in connection with a study of the effect of humidity on the stiffness of organdie.

CONTENTS

I—INTRODUCTION

The quality of the finish of a cotton fabric is a matter that concerns its appeal to the judgment of the buyer on the evidence of his senses. The judgment depends on time and place, on seasons, fashions, and personal and racial predilections, so that it would be futile to pretend to replace expert or aesthetic appreciation by the numerical result of a physical test. The evidence of the senses, on the other hand, depends on the physical properties of the material, so that physical measurements can be of great value in providing data upon which to exercise judgment. Thus the personal judgment of strength is now largely replaced by the numerical result of a physical test, and recent work at this Institute has shown that the visual judgment of lustre and whiteness may advantageously be augmented by physical measurement.

So far, however, those qualities of a fabric included under the name "handle" have not been discussed in terms of ultimate physical properties; the work described in the present paper was initiated in order to remedy this deficiency.* As a result, personal judgment of those aspects of "handle" that can be included under the generic name "stiffness" can now be reinforced by simple physical measurements. The aspect that involves the response to stroking, however, is not here considered; this depends on frictional properties and it will be discussed in a separate communication.

The various quantities that may be used as measures of the stiffness of a fabric are enumerated below.

(1) The Bending Length, c.

The way in which a fabric drapes or hangs depends largely on its stiffness, i.e. its resistance to bending, and on its weight. The most important measurement described in this paper is the determination of the ratio of these two quantities expressed in suitable units, and this ratio, or for convenience its cube root, may therefore be regarded as a quantitative measure of the property on which the "hang" of the fabric depends. The cube root of the ratio is conveniently termed the "bending length," for it measures the length of fabric that will bend under its own weight to a definite extent. The stiffer the fabric, the greater is the length necessary to ensure sufficient bending, so that a high value of c corresponds to a stiff fabric, and *vice versa*.

*The present method has been in use since early in 1927. Meanwhile, three papers have been published dealing with the measurement of flexural rigidity by the deflection of a cantilever. The mathematical formulations and practical methods are, however, substantially different and not as fully worked out for application to textiles.

The actual determination of bending length is readily done with the aid of a simple testing instrument, and it is suggested that this measurement could usefully be adopted as a routine test for cloths.

(2) The Flexural Rigidity, *G*.

While the bending length is the measure of stiffness that determines the draping qualities of the fabric, the flexural rigidity is a measure of the stiffness as appreciated by the fingers. It is, in fact, the resistance to bending mentioned in (1) above—the couple on either end of a strip of unit width bent into unit curvature, that is, the pair of forces acting in opposite directions that would be appreciated as a pressure on the skin if such a bent strip were held between the finger and thumb.

The evaluation of flexural rigidity is extremely simple when the bending length has been measured. It was pointed out above that the bending length is the cube root of the ratio, resistance to bending divided by the weight per unit area, hence the only additional measurements required are the weight and area of the specimen.

For routine tests of stiffness the measurements mentioned above are sufficient. For a more thorough study, however, and for special purposes, the quantities mentioned below may be determined.

(3) The Thickness, *d*.

All the succeeding quantities depend on the measurement of the thickness of the fabric, and this property is also of interest on its own account, since it is appreciated in handling the material. The measurement of thickness is therefore discussed in detail.

(4) The Hardness, or Resistance to Compression, *H*.

The thickness of a fabric depends on the pressure applied to it, and the relation between these quantities is a measure of the hardness of the material. In order to obtain a numerical value, the thickness is measured under two definite pressures, and the ratio of the difference of pressure to the difference of thickness is used as a measure of the hardness.

(5) The Bending Modulus, *q*.

The flexural rigidity described in (2) above is highly dependent on the thickness of the specimen, for it takes more force to bend a thick strip than a thin one; in fact, doubling the thickness increases the flexural rigidity eightfold. When the thickness of the fabric is known, however, it is possible to calculate a quantity that is independent of the dimensions of the strip. For a strip of metal or other uniform (homogeneous and isotropic) material this quantity expresses the specific resistance of the material to bending and is definitely related to the resistance to extension. For a structured material like a fabric, however, the modulus so calculated has not quite the same meaning, but it may still be used to compare the stiffness of the material or weave in fabrics of different thickness. In cotton cloths it may be regarded as a measure of the compactness, and is mainly dependent on the degree of adhesion of the fibres and threads.

(6) The Compression Modulus, *h*.

The bending modulus q may be obtained as above for the two directions parallel to the surface of the fabric. From the hardness H may be evaluated the compression modulus h, which is a similar quantity for the direction normal to the fabric surface. This quantity is also a measure of the compactness of the material.

(7) The Density, ϱ.

The density of the fabric is obtained by dividing the weight in grams per sq. cm. by the thickness in cm. It represents a third measure of compactness, but is more influenced by the proportion of space left between the hairs.

(8) The Extensibility, q'.

The resistance to extension of a cloth is a property that affects the personal judgment of handle. The extensibility is expressed by Young's Modulus, obtained from an autographic strip test.

The aforementioned quantities are discussed and their measurement described in the second section of this paper, which also includes a discussion of the actual values obtained from a number of fabrics. Many of these quantities depend on the primary measurement of bending length, so that the determination of this quantity is of the first importance. The method described for this measurement is available for a wide range of fabrics, but for exceptionally stiff or limp materials, or for special purposes, other methods may be desirable. Accordingly, some alternative methods are discussed in the third section of the paper, and as an example of one of them there is described an investigation of the effect of humidity on the stiffness of organdie. The formulæ used for the evaluation of the quantities are given in an appendix, which also outlines the mathematical basis of the test.

II—THE MEASUREMENT OF STIFFNESS

(1) The Bending Length, c.

The method adopted for measuring the bending length is a refinement of the common practice of judging the stiffness of a fabric by the overhang of one or more folds. A photograph of the instrument used for this purpose (the flexometer) is reproduced in Fig. 1a. The platform A is hinged at O and is on its upper surface graduated in centimetres from that point. Fixed to it at an angle of 25° are two equal pointers B, the upper edges of which pass through O when produced. At the outer end of the platform a friction piece bears on the inner surface of a thick circular arc C, of which O is the centre; the front edge of the arc is graduated in degrees from the point level with O. The pillar is surmounted by a horizontal plane D, the front edge of which is a straight line passing through O. The removable weight F fits neatly into a bed made by side pieces, the front edge being practically coincident with that of the plane when there is no specimen between. To avoid draughts, the instrument is used in a glass case with right side and top removed, and with a black or other contrasting background.

Specimens are cut from the fabric to be tested with a razor and template, accurately 6 in. by 1 in. The edges of the template are made to follow the length-wise threads as closely as possible, and a clean cut is made that is not afterwards trimmed. It is desirable that samples should have been handled as little as possible, for bending and folding alter the stiffness and produce lines of crease or weakness that make the result meaningless. Unfilled cloth may usually be ironed under a damp cloth without appreciably affecting the stiffness of the uncreased portions. Many fabrics tend to curl and twist when cut into small specimens, and this affects both the regularity and the physical meaning of the test figures. Alternative methods are discussed in Section III to meet special difficulties of this kind.

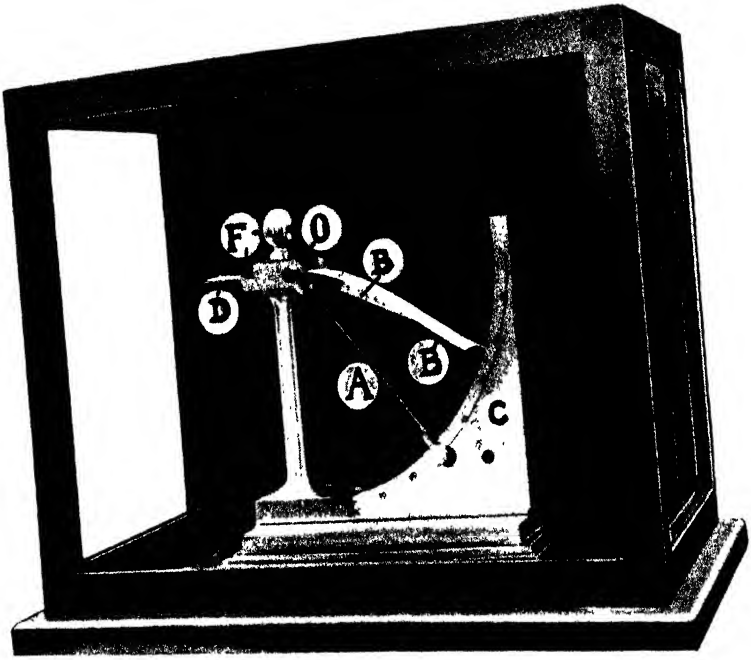


Fig 1a Original Model of Flexometer.

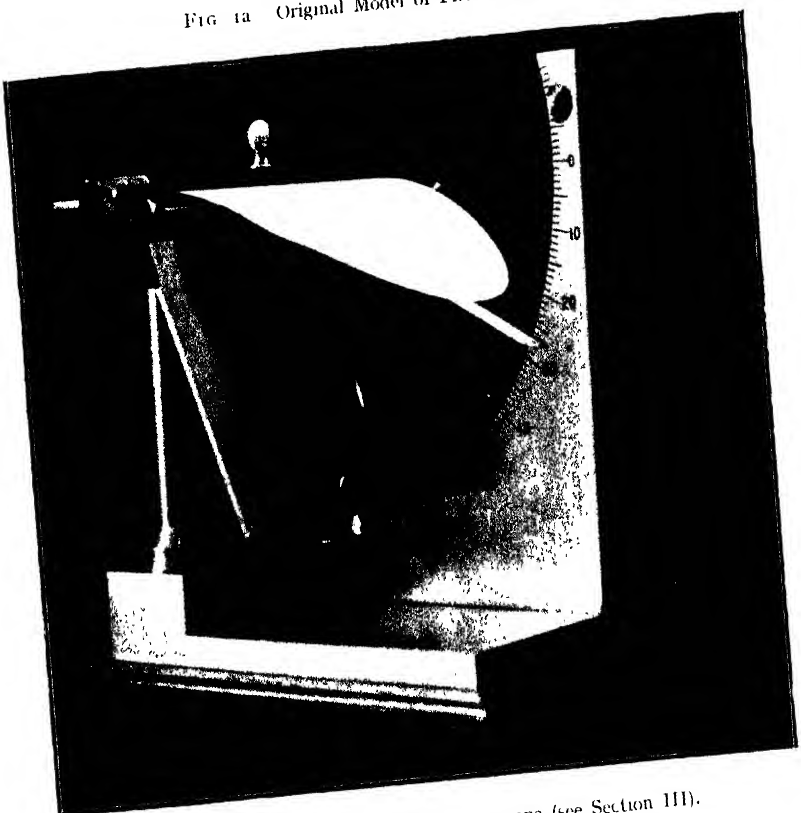


Fig 1b. Recent model for wide specimens (see Section III).

With the platform horizontal, the specimen is laid on it and the plane D, the front end being adjusted to one of the graduations, say, 10 cm. for a stiff material. The weight F is placed in position, and the platform depressed to leave the strip overhanging. The upper edges of the pointers are then brought into line with the end of the specimen, and the reading is noted. If the end twists at all, the pointers are aligned with the midpoint. The specimen is then removed from the instrument and replaced with the other side up, when another observation is made. The two angles may differ owing to the weave or to a curl in the strip, and the mean angle is used to obtain the bending length by reference to Appendix A. The observations are then repeated on the same specimen with the ends reversed, so that two values of the bending length are obtained on any one specimen from four readings of angular deflection. It may sometimes be useful to convert the single observations to bending lengths in order to show the difference between one side and another in a fabric such as a warp-faced satin, but more often the difference is due to a curl or kink, so that the apparent difference in bending length is usually fictitious. The mean result generally depends little on the stage at which the angle is converted, for the relation is nearly linear over the useful range. For routine, it is quicker to average the four angles from each specimen before converting to bending length. The figures so calculated (one for each specimen) can then be used to judge the variability and can be related to the separate weights of the specimens.

The number of specimens necessary to give a representative value for a fent depends on the regularity of the results and the degree of accuracy demanded. Five in each direction, warp and weft, is a reasonable number. The length overhanging should be chosen to give a deflection of 20°–30°; or more for flimsy materials, since very short lengths also mean increased errors of observation. To get higher accuracy from a limited number of specimens, however, it may sometimes be useful to repeat the test on each with two or three different lengths of overhang, as the maximum bending then occurs at different parts of the strip, but if the material is available it is better to cut sufficient specimens, and to take them over as wide a range of position as possible, to get the best sampling.

An illustration of the test is afforded by the following measurements made on six warp-way specimens cut from a fent of mercerised "Tarantulle," tested at 68% R.H. with 10 cm. overhang.

Table I

Specimen	Angles				c in Centimetres		
	End 1		End 2		End 1	End 2	Mean of Ends 1 and 2
	a	b	a	b			
1	27·9	32·0	27·3	33·5	5·943	5·902	5·923
2	21·7	27·9	25·4	29·3	6·427	6·180	6·303
3	28·7	32·2	26·1	32·2	5·902	5·984	5·943
4	27·0	31·1	31·5	34·2	6·026	5·702	5·864
5	28·5	31·3	26·9	33·0	5·943	5·943	5·943
6	26·8	31·4	29·1	29·8	6·012	5·984	5·998
	Mean angle 29·39°, $c = 5·998$				Mean value of $c = 5·996$		

In the above example the range of c on the six specimens is 0·439, corresponding to a standard deviation of 0·17 and a probable error of the mean of a five-specimen test (as recommended) of 0·08.

Between dropping the platform and taking the reading the procedure should be neither hurried nor unduly delayed. There is a slight settling down of the hanging end, depending on the material. Thus observations at 70% relative humidity on the above material (10 cm. overhang) gave an immediate reading of 26°, 28° at 30 seconds, 29° in 90 seconds, 36° after 2 hours, and 47° after 2 days. The result of the dynamical test (described in Section III) corresponds to an instantaneous reading of 23°. This time effect generally increases with the degree of bending, the softness of the material, the length used, and the humidity, but no attempt has been made to establish quantitative relations. No noticeable variation occurs when a leisurely routine is adopted, allowing about 10 seconds of free hanging (there is no need to time it). This procedure may slightly magnify the differences between stiff and soft cloths, but only in the way that they would be magnified in judging them by appearance or feel. It is most important that a swift downward swing should be avoided, for fabric will not recover completely from over-bending.

Like all textile measurements, the test for bending length is preferably done in an atmosphere of controlled humidity, failing which the hygrometer reading should be noted. In order to bend a fabric, one must bend and stretch the hairs as individuals, at least in so far as the structure binds them into a compact mass. According to quantitative relations given in other papers, the resistance both to bending and stretching decreases materially with the humidity, and consequently the stiffness of cloth must do the same. This is an important practical aspect of the question, for the moisture content can vary over a wide range without producing a definite feeling of dryness or moistness. A sample that should have a firm handle will be judged more favourably when dry than when moist, and *vice versa*.

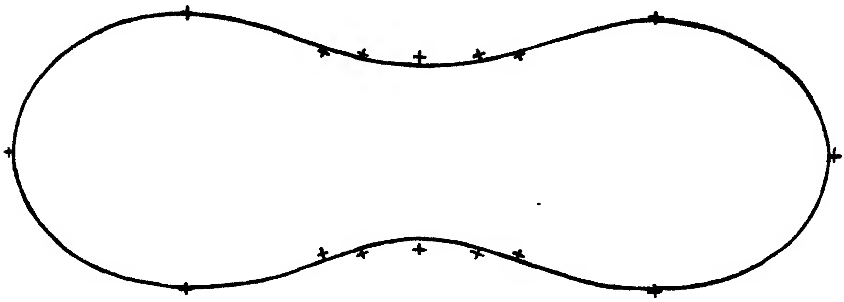
The swelling caused by moisture absorption also enters into the question, making a compact cloth thicker and partly counteracting the tendency to "fall" or become limp. Internal slip may be minimised by the swelling and increased frictional grip of the hairs. In flimsy fabrics the bending of the hairs accounts for most of the stiffness, while in hard fabrics the stretching has more effect. The net result on the stiffness test of changes in humidity will therefore be complex, and will vary with the fabric. In a rough and general way, the effect is determined by the known relations of single hairs, but no universally valid correction could be given to reduce readings to their equivalent at a standard humidity. It is advisable to condition and test specimens in an atmosphere at or near 70% R.H., or some other constant humidity.

If the humidity effect is of special importance, the quantitative relations must be obtained by special tests, such as those described on organdie in Section III.

A woven fabric has different properties in the warp and weft direction; the threads generally differ in count, twist, number, crimp, and sizing, so there is no reason to expect a relation between the bending lengths measured in the two directions. Most fabrics will hang or drape quite differently according to the direction along which they are supported, and the two measurements are separately significant in describing the stiffness.

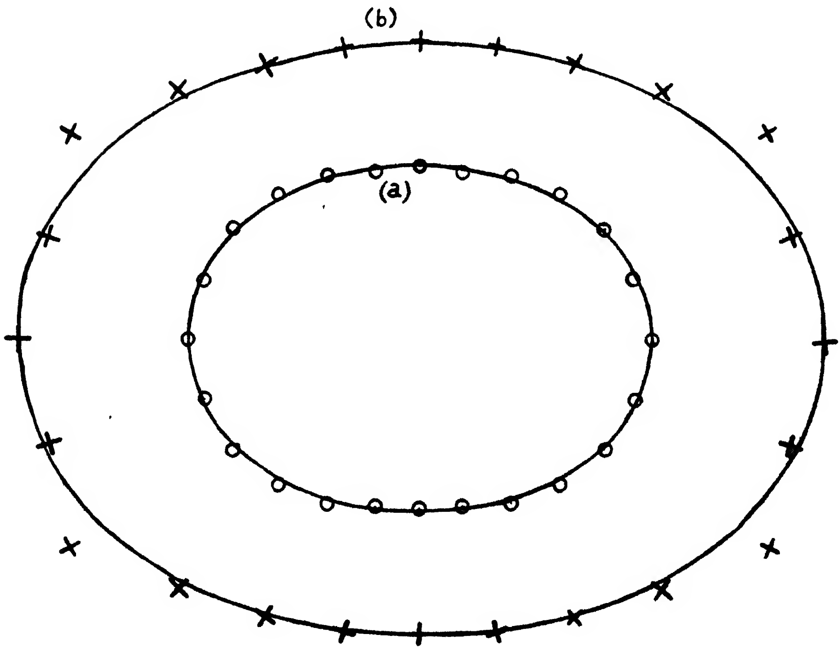
The stiffness of a fabric in a direction oblique to warp and weft depends on the values obtained in these two directions, and a formula has been derived that enables the value for any direction to be obtained when the values in

the warp and weft directions are known. This formula has been confirmed experimentally. Template specimens were cut from a finished lawn at various angles to the warp, and these were tested in the usual way. In Fig. 2, the mean values of the flexural rigidity, G, in each direction are plotted, and the theoretical curve is shown fitted to them. For this material the two directions differ more than usual, and this ensured a good test of the form of the relation. In Fig. 3 the values of c obtained with a satin drill at intervals



Curve $1/G = \left(\frac{\cos^2\theta}{\sqrt{G_1}} + \frac{\sin^2\theta}{\sqrt{G_2}}\right)^2$

FIG 2: Plot of G measured on Lawn



$$c = c_1\left[1-(1-k^2)\sin^2\alpha\right]^{-\frac{2}{3}}$$

FIG. 3

Plot of c measured on Satin drill. (*a*) Bleached. (*b*) Starched and ironed by hand.

of 15° are plotted along with the theoretical curve deduced from the usual measurements in warp and weft directions. It is evident that these two measurements determine the stiffness in all directions, and hence for testing purposes there is no need to make measurements on specimens cut obliquely.

From this formula for the stiffness in any direction there can be deduced another for the stiffness averaged over all directions; this is the value that should be used when it is desired to specify the stiffness of the fabric as a whole by a single figure. The necessary formula is given in the appendix to this paper; actually the geometric mean of the values for the two directions is a close approximation to the value given by the formula, so that for practical purposes it is sufficient to multiply together the separate figures for the warp and weft directions, and take the square root of the result. It is simpler and generally sufficient to use this average figure when, as is usual, warp and weft values do not differ greatly, but it is easy to apply the correction of the formula if it should be considered necessary. Thus for the finished lawn mentioned above, the values of c were—Warp 3·10, weft 1·86, and the geometric mean 2·40 would be used to describe the stiffness generally. The exact formula would give the value 2·47. Again, for the starched satin drill, the formula value of c differs only by 0·8% from the geometric mean of the values for the warp and weft directions.

It has been suggested that five specimens should be cut in each direction to obtain a representative value of the bending length, but no invariable rule can be laid down on this point, for the number depends on the purpose of the test and on the regularity of the material. If it is merely desired to know what figure might be expected from a certain kind of cloth, then three tests on each of a number of samples should suffice to determine the range of reasonable variation in either direction, If the object is to measure the extent to which the finish of a cloth is affected by various lubricants in the size or by various steeping processes, then many more tests would be necessary. In most comparisons there is little point in high statistical precision, for cloth cannot be reproduced very exactly, either in manufacture or finish.

The variability of the stiffness of 6 in. by 1 in. specimens may be measured by the standard deviation of the bending length, taken as 0·43 times the range of 5 (the difference between the greatest and least value), and expressed as a percentage of the mean. On small fents of moderately firm fabrics in undisturbed condition, this is usually about 5%, making a probable error of the mean of five values some 1–2 per cent. It might be said that, between similar fabrics, a difference in c of less than 1% can mean nothing, since it could not be avoided by the most painstaking control of production; 10% represents an appreciable difference in handle. The value is therefore usually given to three figures.

The standard deviation of 5% mentioned above refers to the general experience of variability in small fents about one square yard or less, and more variation may be expected along a piece. For example, tests were made on a 15-yard length of satin drill at five points 3 yards apart, three warp and three weft specimens being cut at each point and tested for stiffness, weight, and thickness (as described below). A certain tendency was found in the warp for neighbouring specimens to be similar, but the variations in the weft were quite random. The values at the two ends (six specimens to each value) were, for the warp 2·85 cm. and 3·10 cm., for the weft 2·19 cm.

and 2·20 cm. The former is a significant difference and illustrates the necessity for wide sampling, and the futility of numerous tests on a small fent.

The bending length, c, is not the only quantity by which the "hang" of a fabric might be expressed. In the mathematical analysis, the formulæ give immediately the quantity $S = c^3$, the ratio of flexural rigidity to weight, and this would have been used had it been otherwise suitable. It gives, however, a very skew distribution which is a great inconvenience in interpreting results. Attempts were made to judge the differences between fabrics from which it appeared that ratios rather then differences of S were equally appreciable over the range from soft to stiff fabrics. (This appears to be fairly generally true of sensory perceptions). For all the earlier work the quantity $\log S$ was used, and proved most convenient in the reduction and analysis of observations. On this score, the bending length c is a little inferior to $\log S$, but much better than S. It gives, however, a neater expression, more easy to visualise than $\log S$. For the same angular deflection the length of the overhanging strip is simply proportional to the cube root of S, i.e. to c. This quantity has been used as the prime measure of resistance to bending, both by Hummel and Morton[1] and by Petersen and Dantzig,[4] so that some possible future confusion has been avoided by adopting it for the present work.

The measure of variability also depends on the quantity used to express the observations. In the warp-way specimens of the satin drill (above), the variability of S or c^3 was 17%, of c 5·4%, while that of the weight was only 1·2%, of thickness 1·7 per cent. It was found that the bending length and the weight of specimens were well correlated (coefficient 0·7), but the variations of thickness were more localised and random.

Sources of variation are numerous in the production of a nominally uniform cloth. In manufacturing there are factors such as counts of warp and weft, picks and ends, weight of size, and warp tension, and in bleaching and finishing, factors of concentration, reaction and temperature of liquors, non-uniform circulation in baths, and the action of machines. These result as far as stiffness is concerned, mainly in variations of weight, compactness, and wax content. In well controlled production they probably do not occur to a much greater extent between different pieces than within the same piece, so that when batches or pieces vary significantly as a whole, it is reasonable to look for a definite cause; this is one of the main routine applications to which this test is suited.

Two sets of figures are available on such points, one illustrating normal regularity and the other an evident irregularity ascribable to a definite and avoidable cause. The former concerned fents from three pieces of a given mark (long-cloth with 6% starch filling), which gave values of c—Warp-way 3·020, 3·119, 3·055; weft-way 2·410, 2·529, 2·438. The other set concerned a fine calendered muslin in which stiffness was a desirable quality, and in a batch of which some pieces finished quite soft for no known reason. Differences of over 25% in warp and weft directions were closely correlated with differences of wax content, and both with thickness but not with weight. The relations are shown in Fig. 4. On investigation, the variations were explained by hitherto unrecognised variations in the weight of size put on the warp. More size meant more fat left after desizing, and also a looser construction, both lowering the stiffness of the finished piece.

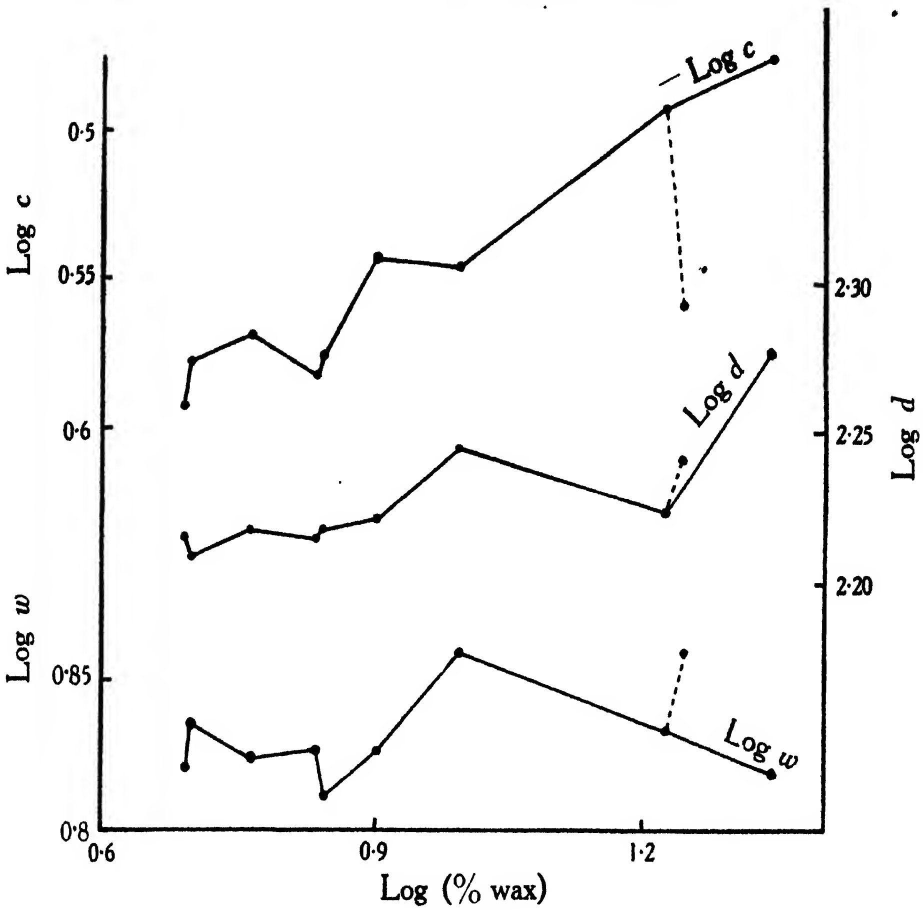


FIG. 4

Wax contents. Values from 10 pieces nominally the same.
No. 9 was very irregular and the mean values have little significance

(2) The Flexural Rigidity, *G*.

The flexural rigidity measures the actual forces produced in bending the material; thus two fabrics may bend to the same extent under their own weight, but the heavier of the two will exert more resistance to bending, say, by the fingers, and so feel stiffer. The only additional measurement required is the weight of the fabric, whence the flexural rigidity can be calculated from the equation $G=wc^3$, where G is the flexural rigidity, w is the weight of the fabric in grams per sq. cm., and c is the bending length. The weighing of specimens is therefore recommended as a regular routine in the stiffness test. It may be done on an analytical balance, in the same atmospheric conditions as the test itself, but no great precision is necessary and other kinds of balance may legitimately be used.

As an example of the value of this quantity, the following figures for a grey calico and a lighter aircraft fabric may be compared. The calico gave values of c warp-way 2·70, weft-way 2·14; the figures for the aircraft fabric were 2·70 and 2·12. The weights were 12·1 mgm. per sq. cm. for the calico, and 6·32 mgm. per sq. cm. for the aircraft fabric, so that the flexural

rigidities were warp-way 236, weft-way 118 for the former, and warp-way 123, weft-way 60 for the latter. While the fabrics were therefore identical so far as draping qualities were concerned, the calico would be much the stiffer as measured by the fingers.

(3) The Thickness, *d*

For the measurement of thickness, a micrometer dial-gauge was used, with a scale divided into units of 1/100th of a millimetre, a base plate of several square inches, and a removable upper plate or pedal. Three pedals were used, with circular plane ends of diameter 0·1, 0·25, and 1·0 inch. A small compressive force is normally applied by a spring inside the gauge, and by the weight of the pedal. This force can be diminished almost to zero by hanging a weight on the operating lever, or increased by placing disc weights on the spindle that carries the pedal.

In order to evolve a satisfactory method of measurement, observations were made on a satin drill with all the available combinations of area and pressure, which are shown below.

Table II
Areas and Pressures of Gauge Pedals

Pedal area, sq cm.—	5·067		0·3167		0·0507	
	Load gms.	Pressure gms/cm.²	Load gms.	Pressure gms/cm.²	Load gms.	Pressure gms/cm.²
Counterpoised ...	9·660	1·906	3·750	11·84	2·885	56·94
Unweighted ...	26·42	5·213	20·51	64·76	19·65	387·7
Weight 1... ...	40·18	7·929	34·27	108·1	33·41	659·2
Weights 1+2 ..	53·88	10·63	47·97	151·5	47·11	929·6
Weights 1+2+3	79·26	15·64	73·35	231·6	72·49	1430
Weight 3 ...	—	—	45·89	144·9	—	—

The results are given in Table III in microns ($\mu = 10^{-4}$ cm.), each figure being the mean of 30 measurements on as many strips of 6×1 inches cut from a 15 yard length of cloth. The average standard deviation was 11·8, and the probable error of the mean 1·5.

Table III

Pedal	Large	Medium	Small
Counterpoised . ..	660	569	453
Unweighted	584	488	420
Weight 1	559	470	404
Weights 1 + 2	544	458	394
Weights 1 + 2 + 3 ...	529	443	381

It is evident from the table that under a light pressure over a large area the thickness is very sensitive to the pressure; this is due to the fact that contact is made over comparatively little of the surface. When the protruding portions are pressed flat and the foot comes in contact with more of the surface, the variation with pressure diminishes.

Since the thickness of a cloth is variable, the measured thickness is determined by the thick or hard places, and hence the larger the pedal the greater is the chance of including thick spots, and therefore the greater the average measured thickness. For an irregular incompressible fabric, the underlying theory of the effect of the size of the tested specimen is identical with that of the effect of the length of the specimen on the breaking load; this has been discussed in an earlier paper.[5] As an example, the thickness of

a starched twill under low pressure was 417 μ under a foot 0·1 in. in diameter; under a foot of 1 in. diameter it was 444 μ, agreeing with the theoretical value of 445 μ deduced from the measurements with the smaller foot.

On a uniform compressible fabric the results from different pedals would be a definite function of the pressure (total force divided by the area), but would be independent of the size of the pedal. Actual fabrics, however, are both irregular and compressible, so that most of the compressive force is taken by the thicker portions, and the effective pressure is greater on a larger pedal. As the compressibility of thick and thin places may be consistently different, the relation between thickness measurements under different areas and weights is very complex, and no simple general rules can be given.

It should be remembered further that the cloth under the pedal consists of threads that continue beyond it, so that an edge effect is to be expected. At the boundary between the compressed and free portions the threads have an upward component of tension, a resistance to compression proportionately greater on a smaller area. On the other hand, a small pedal may cause some sideways displacement in a soft cloth, an edge effect acting in the other sense. These several factors of irregularity, compressibility, and edge effect, will vary in importance with different materials, areas, and pressures. A more detailed analysis is possible, but would serve no useful purpose.

The conditions chosen for a standard measurement should be a compromise, more or less arbitrary, avoiding the undue influence of any one factor. In this work, unless otherwise stated, the measurements have been made with a foot of $\frac{1}{4}$ in. diameter without extra weighting; that is, under an area of 0·3167 sq. cm. and a load of 20·51 grams.

A method that might be mentioned for getting over the indefiniteness of thickness due to irregularity is to measure the thickness in multiple layers. The random variations compensate each other, and the average thickness per layer is usually less than that measured on single layers. This is illustrated by the following figures for the thickness of stockings, measured in four layers and singly, under the series of weights given in Table II, medium foot.

Fourfold ...	404 ...	358 ...	345 ...	335 ...	321m icrons
Single ...	445 ...	395 ...	380 ...	370 ...	355

On the other hand, the thickness measured on multiple layers of varnished electrical tape was greater than on single layers. This material is so hard that irregularities over a considerable area affect the contact at the measuring point, so effectively increasing the area of the gauge foot.

The method is adopted by the Electrical Research Association for testing insulating fabrics, but has not been used here, for it introduces another arbitrary factor and more danger of edge effects. There is no absolute definition of the "thickness" of a fabric, and it is sufficient, for comparison, to adopt the simplest reasonable conditions of measurement and maintain them invariable.

There is still room for personal variations in the manner of lowering the pedal. This has been done steadily without drop, though the American Society for Testing Materials recommends dropping the pedal from a constant height of $\frac{1}{8}$th of an inch.

(4) The Hardness, *H*.

The relation between thickness and pressure—using the medium foot—has been observed on a number of fabrics and is shown by the curves in

Fig. 5. Differences of surface and texture are reflected in the shape and slope of the curves, all of which are more or less concave upwards. Between the first two points the rapid change is characteristic of the surface rather than of the body of the cloth. To some extent this is an index of the roughness of the surface, as shown, for instance, by the curvature of the graph for gingham compared with the straightness of the graphs given by the smooth, calendered "rayonne" and lawn. The difference in these two measurements is most useful in characterising raised fabrics, and may be used as a measure of the "nap," e.g. in the flannelette.

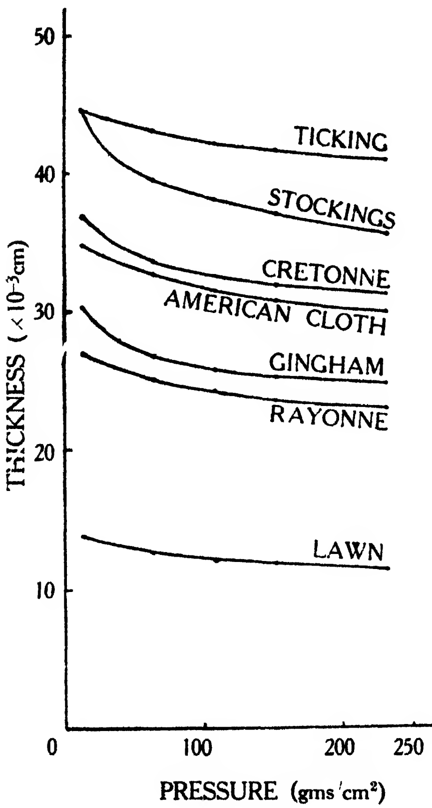


Fig 5a

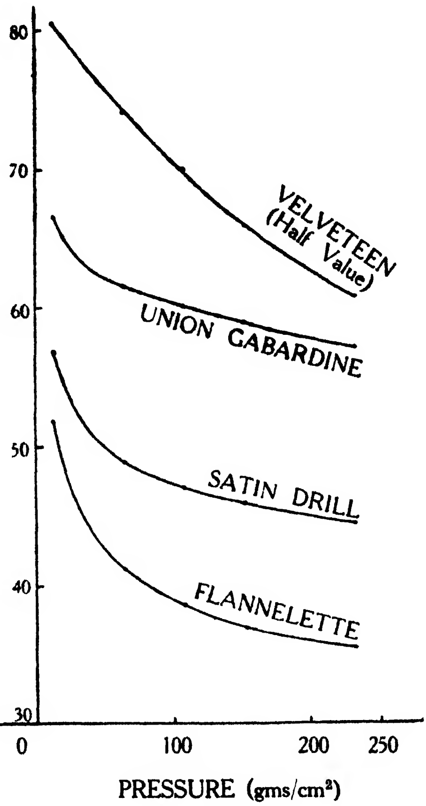


Fig 5b

At the other extreme, the fibres are pressed into contact and are themselves being compressed. It is considered that the slope between the second and fourth points is most characteristic of the texture, and this has been adopted as a measure of another factor in the "feel" of the cloth. After each thickness measurement without a weight on the pedal, another reading is taken at the same spot with weight No. 3 added. The ratio of the difference in pressure (80·14 gms./cm.²) to the difference in thickness thus observed is a measure of the "hardness," H, such as may be appreciated by pressing with a finger tip.

The pressure difference adopted here is arbitrary and may be varied for special purposes. For example, schreinered and varnished fabrics are so hard that a much greater pressure must be used in order to make a comparison sufficiently sensitive, and to test the body of the cloth rather than

the surface irregularities. The same applies to sheets of continuous material, starch film, cellulose sheet, or paper, for which the smallest foot is more suitable.

(5) The Bending Modulus, q.

In the section on "flexural rigidity," a comparison was made between a grey calico and an aircraft fabric; the two fabrics fall under their own weight in just the same way, but the heavier fabric is appreciably more resistant to bending between the fingers. There are other differences, however, that would be described by saying that the former had a "fuller" handle, while the latter was "thin and papery." The measurement of thickness permits of a quantitative expression of such differences.

The intrinsic stiffness of the material of the fabric can then be expressed by the modulus—

$$q = 12G/d^3.$$

The weight and the thickness are measured without reference to the directions of the threads, and it has been found best to combine the warp and weft bending lengths by the average, as discussed in (1) above, before calculating the flexural rigidity and the bending modulus. The latter figure is by no means a mere theoretical abstraction; it can be appreciated by handle more easily perhaps than either of the others. It is the quality generally called "paperiness," a good descriptive name that might with much truth be given to this modulus.

The value for normal fabrics is of the order 100. A hard paper gave the value 30,110, and the nearest fabric, a tulle "parchmentised" with sulphuric acid, 17,350; as examples of mechanical stiffening only, a white schreinered satin, 4,228, and a beetled shirting, 2,343. These are all very "papery" materials, and that kind of stiffness is very easily distinguished in handle from stiffness due to thickness, such as that of a conveyor belting with $G=26{,}420$ and $q=30$ only. Comparing the aircraft fabric and the calico, the former had a thickness of 139 μ, hence $q=12\times10^6\times86 / 139^3=386$. For the latter the thickness was 324 μ and $q=59$. Thus for these two fabrics the values of the bending length, flexural rigidity, and bending modulus show that their draping qualities are similar, that the calico is the stiffer to the fingers, and that the aircraft fabric is more "papery" than the calico. These qualities could, of course, have been distinguished by handling the fabrics; the advantage of the methods here described is that definite numbers can be ascribed to these qualities, and so comparisons can be made much more easily and with less doubtful result when the differences between the materials are not so pronounced.

(6) The Compression Modulus, h.

Compression may be expressed as a strain, that is, the difference in thickness divided by the original thickness. The ratio of stress (difference in pressure) to strain gives a "Young's Modulus" for the material in a direction normal to the surface, which may be compared with the bending moduli obtained for the warp and weft directions. The ratio, which may be called the "compression modulus," h, depends mainly on the compactness of the material, and is in fact found to be highly correlated with the bending modulus. It is, however, more influenced by the surface irregularities of hard fabrics.

(7) The Density, ϱ.

If the weight in grams per square centimetre is divided by the thickness in centimetres, the quotient is the weight per cubic centimetre or density, denoted as is usual by ϱ. This is also a measure of compactness, but is more influenced by the proportion of space left between the threads. The bending modulus is rather a measure of the degree to which the fibres and threads are welded together mechanically.

(8) The Extensibility, q'.

In handling a cloth it is easy to appreciate its resistance to extension, and that quantity must affect the personal judgment of handle. The extensibility is expressed by the ratio of tensile stress to strain (Young's modulus), which is obtained from an autographic strip test. This test yields a curve between load and extension that is usually far from straight, the strip being more extensible at the beginning of tension, and to compare with handle and the bending test the extensibility should be judged from the initial slope.

In a rod of uniform material, Young's modulus and the bending modulus are identical. In a fabric the internal structure differentiates resistance to tension from resistance to bending, but a general relation is found between them, stiff cloths being less extensible. Thus Young's modulus was calculated from the load at 1% extension of a series of fents of white satin schreinered at various pressures. A high correlation was found between the tensile and bending moduli, and between both and thickness, as shown in Fig. 6. The resistance to tension is greatly increased by compression of the fabric in a calender, but the resistance to bending is increased very much more.

The close agreement of the two moduli for a structureless sheet has already been demonstrated for starch film.[6] A relation almost as close may be expected in heavily doped fabrics for aircraft or electrical insulation. Flexibility is an important quality of the latter when the fabric is wrapped round moving parts of an accurately machined instrument. It must bed into variations of curved surfaces, the capacity for which involves both extensibility and softness to bending. The stiffness test should be sufficient indication of both qualities.

Flexibility, in the ordinary use of the word, involves not only ease of bending but also the capacity to bend to a large degree without cracking or breaking. There is the same duality of meaning in extensibility. Again, the two quantities are fundamentally the same, the limiting amount of bending being determined by the local extension in the material of the outer surface at the greatest curvature. The measurement of ultimate extension is familiar in tensile tests. A corresponding test for ultimate bending is described in Appendix B.

Characteristics of Various Fabrics

To illustrate various applications of the stiffness test and to initiate a basis of comparison, the values obtained for the several measurable characters relating to "handle" (with the exception of the extensibility) are collected in Table IV. These are derived from measurements on a wide variety of fabrics without special selection, and they include all those examined up to July 1928, except for several special researches separately reported.

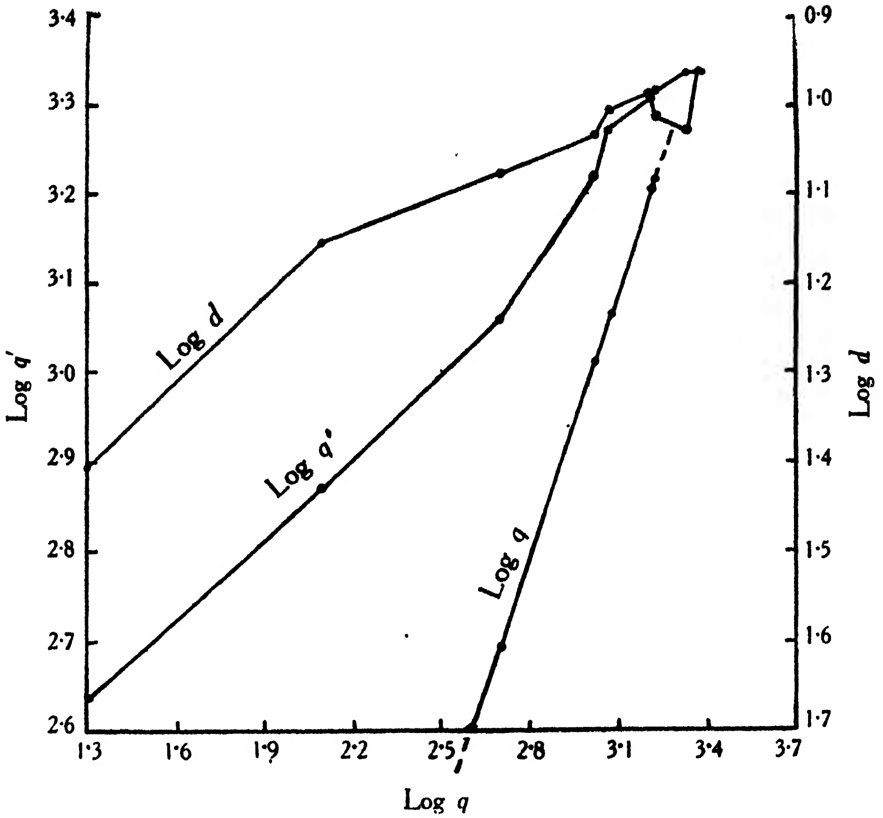


FIG. 6

Stiffness and Extensibility

Table IV

Stiffness Characteristics of Various Fabrics

The entries in the columns are—

w Weight per sq cm, in milligrams, at 70% R.H.

d Thickness in μ (micron = 10^{-4} cm) measured under a foot of ¼ in. diameter; load 20·5 grams.

$\varrho = w/d$, the density.

c The bending length in centimetres, from flexometer reading at 70% R.H.

$G = wc^3$, in mgm. cm., the flexural rigidity.

$q = 12G/d^3$, in kg /cm^3, the bending modulus

H The hardness, the ratio of changes in pressure and thickness in mgm./cm^3

h The compression modulus $= Hd$, in kgm /cm.^{2}

No	Material		w	d	ϱ	c Warp	c Weft	G	q	H	h	Notes
1	Aircraft fabric ...		6·32	139	0·45	2·70	2·12	86	386	134	1·86	L
2a	Calico		12·2	320	0·38	2·64	2·72	235	87	39	1·24	L
3	Calico		18·8	380	0·49	3·35	3·61	790	173	33	1·25	L
4	Calico with size containing tallow	(a)	10·6	262	0·41	3·21	2·80	286	192	43	1·13	L.1
		(b)	10·9	263	0·41	3·29	2·86	316	209	47	1·24	L
5a	Calico, grey ...		12·1	324	0·37	2·70	2·14	169	59	31	1·02	L.2
5b	Water-boiled ...		12·0	299	0·40	2·03	1·94	93	42	32	0·96	
5c	Scoured ...		10·6	272	0·38	2·17	2·06	101	60	31	0·85	
5d	Bleached ...		10·8	263	0·45	2·55	2·03	127	84	34	0·89	B

Table IV (*continued*)

No.	Material	w	d	ϱ	c Warp	c Weft	G	q	H	h	Notes
6a	Mull	3·53	142	0·25	1·92	1·70	21	88	73	1·04	B.3
7a	Satin	7·56	231	0·33	2·64	1·46	57	55	45	1·03	B
8a	Taffeta	8·09	242	0·34	2·09	2·06	72	61	55	1·34	B
9a	Tarantulle ...	8·66	208	0·42	2·25	2·04	85	113	75	1·56	B
10	Low weft sateen	8·70	395	0·22	2·23	1·38	47	9	22	0·86	B
2b	Calico	12·1	319	0·38	2·67	1·86	134	50	42	1·34	B
13	Harvard shirting	13·5	473	0·29	2·94	2·36	246	28	18	0·87	B
14	Long cloth ...	13·7	228	0·60	3·15	3·24	444	450	79	1·79	B
15	Calico	16·0	318	0·50	2·58	2·40	247	93	42	1·33	B
16	Twill	20·0	505	0·40	3·44	2·29	443	41	30	1·53	B
17	Satin drill ...	22·2	470	0·47	2·99	2·17	367	42	35	1·65	B
18	Mull 0·17% wax	6·62	162	0·41	3·91	2·47	199	566	76	1·23	C.4
19	Mull 0·29% wax	6·61	189	0·35	2·99	1·85	86	152	54	1·02	C.4
20	Poplin	10·5	225	0·47	2·69	1·73	105	111	71	1·60	C.5
21	Poplin	11·0	219	0·51	2·62	1·60	94	108	72	1·57	C
22a	Beetled shirting	11·7	142	0·82	3·53	3·17	438	1836	95	1·35	C.6
23a	Beetled shirting	11·7	140	0·84	3·64	3·52	537	2343	94	1·32	C
22b	Before beetling	13·3	395	0·34	2·47	2·45	198	39	36	1·41	B
23b	Before beetling	13·3	405	0·33	2·28	2·47	177	32	42	1·69	B
7b	Satin	7·42	99	0·75	5·06	2·56	347	4228	178	1·77	S
24a	Black satin ...	7·87	234	0·34	2·68	1·38	56	52	48	1·12	
24b	Black satin ...	7·88	118	0·67	4·51	2·09	228	1656	120	1·42	S
25a	Black sateen ...	20·5	486	0·42	2·22	2·15	214	22	30	1·48	
25b	Black sateen ...	21·3	356	0·60	3·33	3·02	681	182	35	1·24	S
8b	Mercerised taffeta	7·45	217	0·34	2·22	2·58	102	120	50	1·09	
6b	Mercerised mull	3·51	132	0·27	2·20	2·21	38	194	73	0·96	
6c	Organdie ...	3·39	100	0·34	5·45	3·89	331	3972	171	1·71	
9b	Linenised tulle	8·66	215	0·40	6·50	5·15	1681	2039	100	2·15	
9c	Acid treated ...	9·33	234	0·40	2·52	2·08	112	104	72	1·68	
9d	Parchmentised	13·3	154	0·86	8·00	6·78	5308	17350	123	1·90	
26a	Long cloth ...	12·2	197	0·61	3·76	2·66	383	606	99	1·95	F
26b	Filling removed	10·8	244	0·44	2·36	1·78	93	81	68	1·66	
27a	Long cloth . .	13·0	206	0·63	3·06	2·46	269	367	97	2·01	F
27b	Filling removed	12·3	242	0·51	2·37	2·14	139	118	71	1·72	
28	Printed lawn ...	5·52	132	0·42	3·10	1·86	774	404	98	1·29	F
29	Gingham (print)	9·80	284	0·35	6·15	2·71	667	350	55	1·56	F
30	Cretonne (print)	12·9	350	0·37	2·76	4·37	537	151	57	1·99	F
31	Flannelette (dyed)	15·9	420	0·38	4·81	2·04	487	79	21	0·87	F
32	Ticking	25·4	437	0·58	3·57	5·11	1985	285	52	2·28	F
33	Velveteen (dyed)	29·9	1450	0·21	2·69	1·85	331	1·3	5	0·69	F
34	Conveyor belting	104	2200	0·47	6·32	6·35	26420	30	8	1·72	F
35	Crepe rayon ...	6·13	179	0·34	1·55	2·82	56	118	65	1·16	F
36	Crepe print ...	10·2	270	0·38	1·67	1·92	59	36	69	1·87	F
37	Crepe shot ...	17·4	346	0·50	3·15	3·35	593	172	42	1·46	F
38	Worsted weft, twill	24·9	623	0·40	2·18	2·09	242	12	26	1·65	F
39	American cloth	32·5	331	0·98	3·23	2·47	733	242	49	1·63	F
40	Graph paper ...	4·83	75	0·64	6·03		1059	30110	211	1·58	F
41	Feeler steel . .	30·2	381	7·93	6·76		9354	$2·03 \times 10^6$			

Notes

L, loom state; B, bleached; C, calendered, S, schreinered; F, normal commercial finish.

1—Each row of No. 4 gives the mean values from four fents having approximately 11% of size on the warp, with increasing amounts of tallow: (4a) mean of 2·4% of tallow to starch, (4b) mean of 11·9% tallow to starch.

2—Similar cloth at successive stages, indicated by a, b, etc., after the same numeral.

3—See also 6b and c below.

4—The extreme cases of Fig. 5.

5—Nos. 20 and 21 are similar cloths containing yarn from the same spinner, of which 20 appears to have been woven with a greater warp tension.

6—Two similar pieces, of which 23 had been given a lime boil, which resulted in a wax content of 0·12% against 0·22% in No. 22

A range of stiffness from 1·81 to 6·35 cms. (mean value of c) is here recorded. Fabrics approaching the lower limit were too soft to be measured

by the standard method, so were tested by the pear cantilever and triangle methods described in Section III. Later, the "hanging heart" method was developed, and is now used for material with a lower value than 2 cms. (which gives 43° deflection with a 4 cm. rectangular cantilever), especially if it tends to curl. The softest fabric that could be found was a knitted viscose, with a bending length of 0·6 cm., measured without difficulty by this method. The highest value does not approach the upper limit that can be measured by the weighted rectangle method (Section III)—in fact, there is no practical limit of stiffness for that method.

The flexural rigidity, G, ranges from 21 for the lightest, a mull of 3·53 mgm. per sq. cm., to 26,420 for the heaviest, belting of 104 mgm. per sq. cm. Other things being the same, the flexural rigidity varies with the third power of the thickness, but if any one cloth is calendered or otherwise compressed, the relation is reversed owing to the rise in specific stiffness. This quantity, q, is the best to consider when it is desired to estimate the effect of the structural factor, which is chiefly the extent to which the hairs cohere. There is also a close correlation between the compression modulus, h, and the density, ρ, most of the values falling near the line $h=10\ \rho/3$; the deviations can reasonably be explained by differences in openness of weave. Cotton cellulose has a density of about 1·5, but few of the materials reach one third of this. About the value 0·5 the hairs are evidently in intimate contact, for the specific stiffness increases rapidly. The greatest density attained mechanically is in the beetled and calendered shirting (0·84), where the finish has almost closed the spaces laterally.

The density and stiffness are influenced at many of the early stages of production; the raw cotton, the counts and twist of yarns, the amount and composition of the size, the number of picks and ends, and the warp tension. Thus the difference between poplins 20 and 21 was associated with lower extensibility and crimp, i.e. greater warp tension, in the stiffer cloth.

The presence of lubricating or cementing matter on the hairs has evidently a big effect. Thus the removal of wax in bleaching increases the stiffness (compare the figures for the water-boiled and bleached calico, Nos. 5b and 5d). The absence of wax is also responsible for the excessive harshness caused by mercerising after a scour. The effect of wax in impeding the development of stiffness in mechanical finishes is shown by the figures for the mulls, Nos. 18 and 19, and the beetled shirting, Nos. 22a and 23a. In the grey state, fats in the size do not appear to have any effect on the stiffness. Starch, as size or filling, has a great stiffening effect, more by cementing the hairs than by virtue of its own rigidity. Dyeing seems to have the opposite effect, the diminution of stiffness being particularly noticeable in the schreinered satins; heavy printing has an appreciable stiffening effect. The swelling in mercerisation brings the hairs into intimate contact, so that the specific stiffness is doubled in the examples given. Sulphuric acid, in the organdie and parchmentising treatments, multiplies the modulus 50 or 100 times, virtually welding the hairs together.

The stiffness of cloth is ultimately dependent on the elastic properties of the hairs, that is, on the sum of the forces necessary to bend and to stretch them. If it is assumed that half the hairs lie in the direction of the strip, then the force necessary for bending alone is $G/2$, where G is the flexual ridigity of single hairs, and the corresponding value of c will be $\sqrt[3]{G/2m}$, where m is the hair weight per centimetre of single hairs. From data formerly

obtained, the value of $G/2m$ for Texas hairs at 70% R.H. is about 6 cm.[3] or $c=1\cdot82$. This agrees with the value for the very flimsiest cloth, the low weft sateen, in which the fibres are apparently so loosely held that they do not take any tension. At the other limit of a compact continuous sheet with elastic properties the same as those of the hair wall material, the value of q would be about 60,000 kgm./cm.[2] It is, of course, impossible to realise such a value, and a nearer approach could hardly be made than that made by the parchmentised sheet with a modulus, $q=17{,}350$. There is no relative movement of the fibres in this, and the lower modulus is sufficiently explained by the degradation of the cellulose, the two orientations of the hairs, and the imperfect uniformity of the sheet. In all other fabrics more or less air space is included, and the hairs take some tension but also yield by relative movement.

The graph paper is also mainly cellulose and is of high quality, thin, tough, and uniform, and gives a value of q half that of the Young's modulus of cotton hairs. It may be noted that the value for feeler steel agrees with the Young's modulus given in tables of physical constants.

The figures of the table yield on perusal many more interesting relations. They express facts that could be appreciated in handling the cloths, but in definite numbers and an impersonal, unified scheme of comparison. More specific investigations have been made, yielding regular curves against some variable factor of treatment, such, for example, as temperature and concentration of mercerising liquor, but the present paper is concerned with the methods of test and their meaning, not with particular problems of finishing in which it may be used.

III—ALTERNATIVE METHODS

In the standard method described in Part I, it is assumed that the specimen of fabric lies flat when unstressed, and that the measured deflection from a horizontal plane corresponds to bending under the weight of overhanging cloth. The construction of many fabrics and the strains produced in finishing often produce, however, a tendency to curl and twist. If the distortion is moderate, its effect is largely eliminated by the two readings with face up and down, but some materials twist into almost helical form. No very precise measurements can be made on such materials, but various modifications of the method have been worked out to deal with those unsuitable for the standard method, and also to increase the range of stiffness measurable.

In the form of the standard rectangular strip with an overhang of 8 cms., fabrics may be tested that give a deflection from 10° to 50°, covering the range of c from about 7 to 3 cms. The length may be varied from 3 cms. to 10 cms., with increase of the range from $1\cdot6$ to $8\cdot5$, which represents over a hundredfold range of the quantity $S=c^3$, the ratio of the resisting forces to the weight. As these two quantities generally vary together, a much greater range in the actual flexural rigidity is covered. The other methods to be described may therefore be regarded as reserves in resource for dealing with special kinds of materials, and not as essential to the stiffness test on the standard instrument, which can deal with a much greater range of materials than, for instance, any one tensile tester.

The first and simplest modification is to deal with very stiff material, such as starched and ironed linen. For this purpose a weight is hung from the free end, using 8 or 9 cm. overhang in order not to foul the quadrant.

The weight may conveniently be a lead hook hung on a loop formed by a thread fastened to each side of the strip of cloth. It may be 0·25 gm. or more according to the material, and there is virtually no limit to the degree of stiffness that can thus be measured. The deflection is observed as usual, and c calculated by the formula given in Appendix A.

There are materials so flimsy that "stiffness" is hardly the word to use in connection with them, and others in which the balance is very unequal, so that the weight of the warp, say, overwhelms any resistance of the sparse weft. Tensile or thickness and compression tests may often be more useful for comparing such materials, but a small increase in the practicable range of measurement by the flexometer may be obtained by observing the deflection of a triangular strip, which gives the same deflection as an equally long rectangle of material with three times the value of S $(=c^3)$. A template, 1 in. wide, was made in the shape of an isosceles triangle, 5 cm. from apex to base, joined by a rectangle, 3 cm. long, to another triangle, 7 cm. from apex to base. Any length of overhang from 3 cm. may be used, and c calculated as described in Appendix A.

The most common difficulty is that presented by the tendency to curl. This may be so pronounced that the strip takes a complete twist, the effect of which on the rigidity cannot be ignored. To inhibit the twist, a long specimen of 20 cm. is cut, the middle marked with a dot, and the two ends placed together to form a pear-shaped loop. The doubled end is placed on the plane D and covered with the weight F, and the deflection measured as before. The depression of the mid-point is much the same as for a strip of the same length as the loop, the length being measured from the nip to the mid-point. The length thus measured, or calculated as equal to 0·4243 times the circumference, may be used to calculate the stiffness (Appendix A).

A material too stiff to be bent thus, but curling badly when tested as a weighted rectangle, may be better dealt with as a triangle weighted at the tip, Equation 6, Appendix A, being used.

The curling is not so pronounced in a broad strip, and an instrument of new design has been made to test strips 6 in. wide. The theory and formulæ are unaffected by this increase in width, and further experience may lead to the adoption of the greater width for general purposes. It has the disadvantage of needing more material, if adequate sampling is to be obtained, but this is counterbalanced by the fact that the warp and weft directions can be tested on the same specimen, 6 in. square. The new form of instrument is illustrated in Fig. 1b.

With the broader instrument, it is also possible to test a specimen cut in circular form, with a segment overhanging (as in Fig. 1b), Equation 3, Appendix A, being used. On this form, measurements can be taken in any direction, and the curl is less pronounced than in any other form.

Really soft fabrics, such as fine hosiery, bend almost to a right angle when overhanging an edge by no more than a centimetre or two. To make their resistance to bending measurable, the amount of bending may be increased. When a strip, 10 cm. long, or less if necessary, is bent into the form of a heart, the ends are turned through an angle of 540°. A perfectly flexible material would fall into a vertical line, but the softest material to be found maintains a very decided loop, the length of which gives a quite satisfactory measure of c. This method has the further advantage of securing the two ends, practically inhibiting curl, while allowing full freedom to bend in the direction desired.

Cloth, if sufficiently stiff and elastic, may be tested by the Searle's pendulum method already described for starch films,[6] whereby the flexural rigidity is determined from the period of vibration. This dynamical method is more laborious, and few cloths are elastic enough to maintain a vibration; it is therefore put forward not as a routine method, but for special research purposes. The decrease of elastic resistance with time affects the measurement much less than in the static test, and the comparison may be used to estimate the extent of the time effect. On suitable materials, it also allows more accurate measurement of the effect of humidity. An example of the latter use is given below.

In all these methods the formulæ developed reduce the observations to the same measure of stiffness, a known function of the forces produced in the bent material, and of its weight. Several experiments have been made to test the identity of c as measured by the different methods, on fabrics, papers, and steel strip. As an example, the following results were obtained on specimens cut from a small piece of mercerised "tarantulle," tested in a room maintained at 70% R.H. and 70° F. The weight of the material was 8·67 mgm. per sq. cm., and its thickness 211 μ. The observations were reduced to values of c by the formulæ given in the Appendix.

Table V

(1) Rectangles			(2) Same as (1), Weighted			(3) Pears			
l	θ	c	l	θ	c	$0{\cdot}424L$	l	θ	c
10	31·6	5·81	9	44·8	5·51	9·34	9·39	28·4	5·77
9	25·0	5·75	8	38·9	5·43	8·49	8·49	22·1	5·74
8	18·8	5·72	7	31·8	5·41	7·64	7·68	16·6	5·75
7	13·0	5·75	6	24·5	5·38	6·79	6·76	11·5	5·73
6	8·4	5·70	5	17·0	5·39	5·94	5·96	7·6	5·86

(4) Triangles			(5) Same as (4), Weighted						(6) Dynamical Test
			7 cm end			5 cm end			
l	θ	c	l	θ	c	l	θ	c	
7	3·0	6·52	7	27·1	5·75				Mean period $T = 1{\cdot}234$
			6	23·8	5·71				$c = 6{\cdot}25$
5	1·7	5·57	5	20·8	5·61	5	14·9	5·79	
			4	16·9	5·61	4	12·0	5·71	
			3	12·9	5·60	3	9·0	5·70	

(1) Standard methods, six specimens. The variations with length are within experimental error and were not consistent in repeat experiments. (2) Weight on end 0·0857 gm, same specimens as (1). The low values may be partly due to handling and were not encountered in other tests. (3) Three specimens, bent into loops of circumference 22 cm., 20 cm., etc. By reversing and turning inside out, four readings are given by each specimen. The measured length of the unstrained loop, l, is not significantly different from the theoretical. (4) Triangles, 7 cm. and 5 cm. long at either end of four specimens. The deflections are too small for accuracy. (5) Same specimens weighted at end with 0·0824 gm. (6) Dynamical test. Four specimens, 5 × 1·5 cm. between grips.

Such comparisons are limited by cloth variability, small changes of condition and after-effects of handling, observational error, and the fact that no one cloth is equally suitable for all methods. There may also be small but real variations of flexural rigidity with the degree of bending, owing to change in shape and in time effects. Several systematic checks were made

to test the validity of the formulæ, including those of the circular and the loop methods, and no consistent differences were found in the results of the static methods, but it is advisable, in close comparisons, to keep the method unchanged if possible. The dynamical test gives higher results according to the degree of elastic imperfection, the difference being inappreciable on steel strip (feeler gauge). The ratio of S $(=c^3)$ for a series of starch films as obtained dynamically and by the standard method with lengths of 8, 7·5, 7, and 6·5 cms. was 113:100:99:99:101.

Effect of Humidity on the Stiffness of Organdie

It is more convenient to study the effect of humidity by the dynamical than the static method. On a suitable cloth, it allows more accurate measurement of small differences, it introduces less danger of after-effects in a series of tests on the same specimen, and the apparatus is more easily enclosed. Organdie is eminently suited to the dynamical test, being so elastic, and the effect of humidity is of special interest. This material is exported to moist tropical countries, and sometimes becomes too limp to please the purchasers.

A specimen was mounted on the Searle's pendulum, which was enclosed in a chamber with controlled humidity and temperature, having two crank arms passing through the lid by which the pendulum could be set in oscillation. The cloth was first dried for a month over phosphorus pentoxide, which was then replaced by saturated solutions of various salts to give a series of increasing humidities. Readings were taken each day for about a week at each stage, but for three weeks at 97% R.H. and seven weeks at saturation, to see if any steady deterioration was caused by long exposure to moisture. None was noted, for the reading after one day was the same as after seven weeks at saturation. On increasing the humidity, the stiffness fell to a minimum in the first day, then slowly rose to a steady value. On decreasing the humidity, the stiffness rose with decreasing speed to a steady value in about a week.

Table VI

Flexural Rigidity of Organdie at Different Humidities and 20° C. (expressed as ratio of $1/T^2$ to value when dry)

Length between grips, 49·6 mm., width 13·7 mm. Thickness (small light foot), before 92μ, after 101μ.

Date	Control	R.H.	G (absorption)	Desorption G	Desorption $G \times (\frac{92}{101})^3$
2/4/27 to 5/5	Phosphorus pentoxide ...	0	1·00	1·31	0·99
	Saturated solutions of—				
12/5	Magnesium chloride ...	34	0·82	—	—
17/5	Sodium dichromate ...	52	0·72	—	—
24/5	Ammonium nitrate ...	65	0·68	0·86	0·65
8/6	Sodium chloride ...	76	0·60	—	—
20/6	Potassium chloride ...	86	0·51	—	—
14/7	Potassium sulphate ...	97	0·27	—	—
30/8	Water	100	0·22	0·22	0·17

The relation for absorption is shown graphically in Fig. 7 and is similar in form and degree to those obtained for the elastic properties of hairs. Up to 80% R.H. the flexural rigidity falls by 5·4% of the dry value for a rise of 10% R.H.

After drying, the thickness was found to have increased by 10%, a change that fully accounted for the increased stiffness after the experiment. Moisture in itself therefore does not appear to destroy the stiff finish permanently, but only while the moisture is retained. The point was important, so nine long specimens were cut along warp and weft, measured by the pear method, and divided into three lots. The first was kept in a chamber over phosphorus pentoxide for three months, the second at 65% R.H., and the third over water. They were then conditioned together for three weeks at 70% R.H. and again tested. Only the last showed an appreciable change, an increased stiffness due to an increased thickness.

Table VII
Permanent Effects of Humidity

	0% R.H		65% R.H.		100% R.H.	
	Warp	Weft	Warp	Weft	Warp	Weft
c before exposure	5·16	3·47	5·16	3·47	5·16	3·47 cms
c after exposure	5·13	3·55	5·16	3·63	5·28	3·95 cms.
Thickness (μ) after exposure	100		101		104	

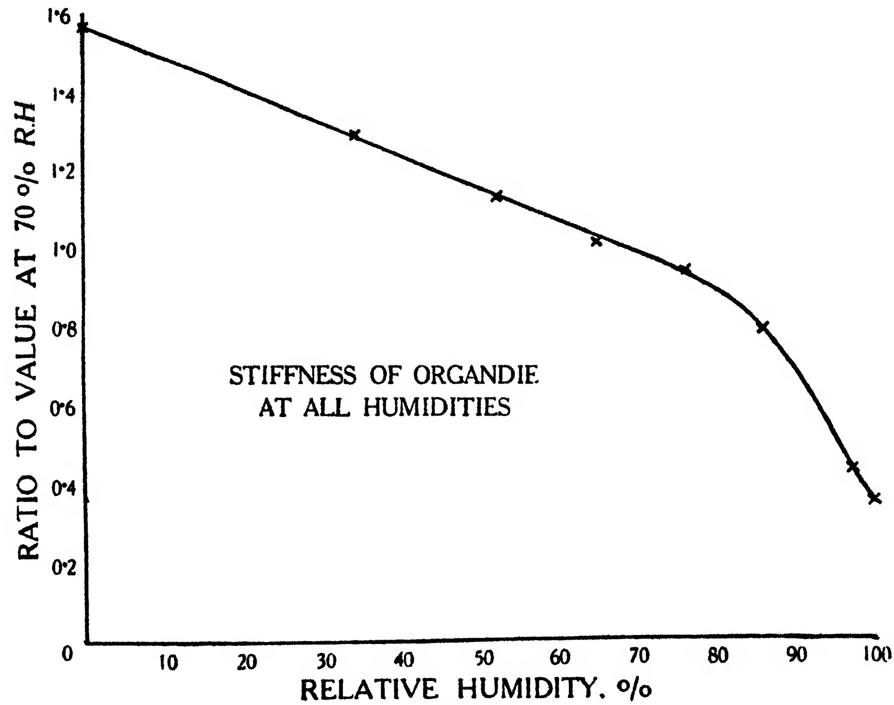


FIG 7

APPENDIX A—REDUCTION TABLES

Rectangular Cantilever

This is the standard method, suitable for most fabrics, and to be used whenever practicable. The length overhanging is adjusted to a suitable value, l, and the angular deflection of the end, θ, is observed, when the bending length

$$c=l.f_1(\theta), \text{ where } f_1(\theta)=(\cos 0{\cdot}5\ \theta / 8 \tan \theta)^{\frac{1}{3}}$$

Table of f_1 (θ)

θ =	0	1	2	3	4	5	6	7	8	9
0		1·928	1·530	1·336	1·213	1·126	1·059	1·005	0·961	0·923
10	0·891	0·862	0·836	0·813	0·792	0·773	0·756	0·739	0·724	0·710
20	697	684	672	661	650	640	630	620	611	602
30	594	585	577	569	562	554	547	540	533	526
40	519	513	506	500	493	487	481	475	468	462
50	456	450	444	438	433	427	421	415	409	403
60	397	391	385	379	373	366	360	354	347	341

Weighted Rectangle

For fabrics too stiff for the standard method, a weight W is fixed to the end of a strip of width b and weight w per unit area.

$$c=l.\left(\frac{W}{3wbl}+0{\cdot}13\right)^{\frac{1}{3}}\cdot\left(\frac{\cos 0{\cdot}93\,\theta}{\tan\theta}\right)^{\frac{1}{3}} \qquad \ldots\ldots\ldots 2$$

The ratio of cos 0·93 θ to cos θ varies so little over the range used in this method that the value at 20° may be assumed in order to use the table of $f_2(\theta)$ given below, when

$$c=l.f_2(\theta)\,.\,(0{\cdot}336\,W/wbl+0{\cdot}131)^{\frac{1}{3}} \qquad \ldots\ldots\ldots 2a$$

Circular Cantilever

This method is applicable only to the larger instrument. It best avoids the difficulty of curling, goes rather lower in range of stiffness than the standard method, and allows measurement of stiffness in any direction on one specimen. If r is the radius of the circular specimen,

$$c=l.f_1(\theta)\,.\,f(l/r) \qquad \ldots\ldots\ldots 3$$

Table of $f(l/r)$

l/r =	0·0	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9
$f(l/r)$ =	0·811	0·814	0·817	0·821	0·825	0·829	0·834	0·839	0·844	0·850
l/r =	1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9
$f(l/r)$ =	0·857	0·864	0·872	0·881	0·892	0·905	0·921	0·940	0·967	1·007

Hanging Heart

Very limp fabrics beyond the range of the cantilever method may thus be tested. The two ends of a strip are clamped together to form a length L into a heart-shaped loop. From the grip to the lowest or mid-point, the undistorted length of such a loop l_0 is 0·1337 L. The actual length l of the loop hanging under its own weight is measured with a cathetometer or otherwise, and the stiffness calculated from the difference $d=l-l_0$

$$c=l_0 f_2(\theta) \qquad \ldots\ldots\ldots 4$$

where $\theta=32{\cdot}85°\,.\,d/l_0$, and $f_2(\theta)=(\cos\theta\,/\tan\theta)^{\frac{1}{3}}$.

Other forms, applications, and dimensions of loops are described below and in Appendix B.

Table of f_2 (θ)

θ =	0	1	2	3	4	5	6	7	8	9
0		3·855	3·059	2·671	2·425	2·250	2·115	2·007	1·917	1·841
10	1·774	1·716	1·663	1·616	1·573	1·533	1·496	1·462	1·430	1·400
20	1·372	1·345	1·319	1·294	1·271	1·248	1·226	1·205	1·186	1·164
30	1·144	1·126	1·107	1·089	1·071	1·054	1·037	1·020	1·003	0·986
40	0·970	0·954	0·938	0·922	0·906	0·891	0·875	0·860	0·845	0·829
50	813	799	784	768	753	738	722	707	692	676
60	661	645	630	614	598	582	566	549	533	516
70	499	482	465	447	429	411	392	373	354	333
80	313	291	269	246	222	197	170	140	107	067

As this method is used only for very soft fabrics, it is practicable to fix on a suitable value of L, say, 15 cms., and to construct a table giving the value of c direct from the measured value of l. This will save labour of calculation when the method is used in a routine way.

These four methods are recommended as best for the types of fabric referred to, which include all types amenable to test. The following methods have also been worked out and occasionally applied; they extend the resources of the test when applied to materials other than fabrics.

Triangular Cantilever

In this form the range of the cantilever method is extended a little below that covered by the standard method.

$$c=l.\ 0{\cdot}6933\, f_1\,(\theta) \qquad \text{.......... 5}$$

Weighted Triangle

Material that is both stiff and curly may be so tested.

$$c=l.\, f_2\,(\theta).\left(\frac{W}{2wbl}+0{\cdot}044\right)^{\frac{1}{3}} \qquad \text{.......... 6}$$

Pear-loop Cantilever

This method may be used for soft, curly material when the smaller instrument only is available.

$$c=l.\ 0{\cdot}212/\tan^{\frac{1}{3}}\theta. \qquad \text{.......... 7}$$

Hanging Loops

Various forms of loop may be used to measure the stiffness of very soft materials, and they have the further advantage of minimising the effect of curl or twist, by the positive grip on both ends. While the heart shape seems the most useful, others may have special applications. The ring shape gives most promise of a practicable method for yarns. Using the same symbols as for the heart shape, l_0 is $0{\cdot}3183\ L$, θ is $157{\cdot}0^\circ\ .\ d/l_0$ and

$$c=L.\ 0{\cdot}133\, f_2\,(\theta) \qquad \text{.......... 8}$$

The last expression holds also for the heart-shaped loop, though the value of the coefficient is a best-fit, not determinable within 1 per cent.

In the hanging pear loop, l_0 is $0{\cdot}4243\ L$, θ is $504{\cdot}5^\circ.\ d/l_0$ and the bending length is given approximately by

$$c=L.\ 0{\cdot}133\, f_2\,(\theta)\ /\ \cos 0{\cdot}87\,\theta \qquad \text{.......... 8a}$$

Stiffness in any Direction

After measuring the value of c in the warp and weft directions, c_1 and c_2, the value in any other direction at an angle α to the warp is given by

$$c=c_1\,(\cos^2\alpha+k^2\sin^2\alpha)^{-\frac{3}{2}},\ \text{where}\ k=(c_1/c_2)^{\frac{3}{2}} \qquad \text{.......... 9}$$

and the mean value

$$\bar{c}=\sqrt{c_1.c_2.}\ \tfrac{1}{2}(k+1/k) \qquad \text{.......... 10}$$

$$=\sqrt{c_1.c_2}\ \text{approximately.}$$

Flexural Rigidity

The weight of the specimen is obtained in milligrams and divided by the area of the template in square centimetres, giving the value of w. When c is expressed in centimetres

$$G=w.c^3 \qquad \text{.......... 11}$$

in mgm. cm., which are convenient units

Bending Modulus

The thickness is measured under the conditions described on p. T388 and conveniently expressed in microns. Then

$$q=12\,G/d^3.\,10^6,\text{ in kgm./cm}^3. \qquad \dots\dots 12'$$

APPENDIX B—THE MATHEMATICAL BASIS OF THE STIFFNESS TEST

Owing to the comparative softness and variability of cloth specimens, the very small deflections used in elastic measurements on metals are unsuitable, and the mathematical analysis of infinitesimal strains is insufficient. To obtain the relation between large deflections and flexural rigidity, the first step is to formulate the intrinsic differential equation. In general, this is of a form that cannot be integrated as a known function, and various

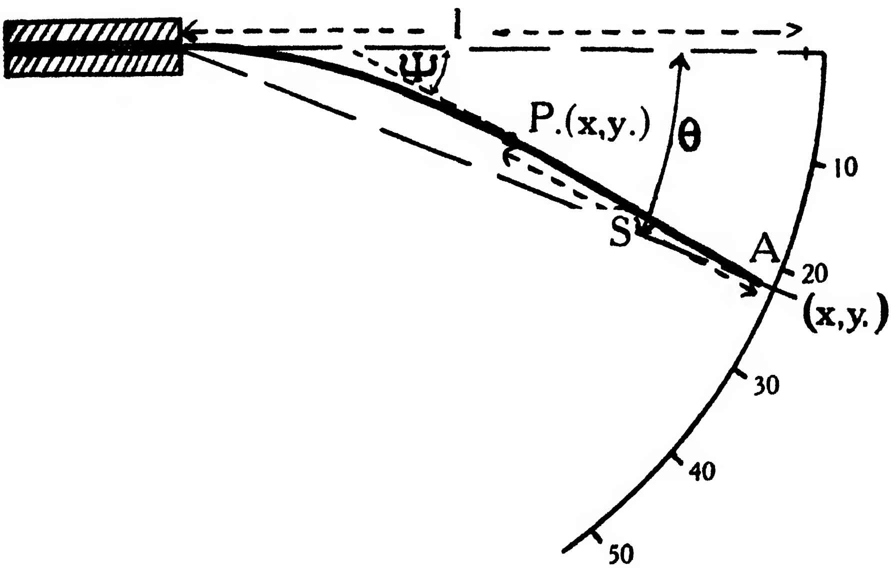


FIG 8

devices have been used to obtain an expression applicable to experimental data (*a*) by expressing the relation in terms of a known tabulated integral, such as elliptic functions, (*b*) by obtaining a series expansion, and (*c*) by modifying the relation for infinitesimal bending so that it remains true for large bending. The last method has been adopted for this work, so that each relation is expressed in a trigonometrical form in which the factors are determined by methods (*a*) and (*b*), by dimensional considerations, and empirically by observations on feeler steel strip.

The specimen is assumed to be a uniform thin lamina, in which the curvature is proportional to the bending moment.* The flexural rigidity, G, is the bending moment for unit curvature per unit width of strip; the weight per unit area is denoted by w. The immediate object of the test is to evaluate the ratio $S=G/w$, in terms of the overhanging length of the

*This assumption may be emphasised as the basis of the following analysis, in which no consideration is taken of the actual deformations in plates of finite thickness of homogeneous material. Thus the modulus q is descriptive of the material as a whole but bears no known relation to the local stress-strain relations throughout the fabric.

specimen, l, and the angular deflection from the horizontal, θ, of the end of the strip. The bending length, c, is then $\sqrt[3]{S}$.

(1) Rectangle Bending under its own Weight*

This is the standard and simplest test, which is shown diagrammatically in Fig. 8. For infinitesimal bending, the usual expression obtained is

$$S = l^4/8\delta \quad \text{.......... 1a}$$

where δ is the depression of the free end. As the deflection increases, this formula gives too high a value for S, since the moment or leverage of the weight is diminished by the bending. If the relation is obtained in terms of θ, infinitesimal bending still being assumed, the formula becomes

$$S = l^3/8 \tan \theta, \quad \text{.......... 1b}$$

which remains a good approximation over a greater range, but still needs correction for large deflections. The simplest means is by a factor reducing to unity for $\theta = 0$ and decreasing with θ at a rate increasing with θ: for which a suitable form appears to be $\cos m\theta$, where m is a fraction to be determined.

If s is the distance of a point P along the strip from the free end, ψ the angle between the tangent there and the horizontal (see Fig. 8), the curvature is $d\psi/ds$ and the bending moment $-G.d\psi/ds$. When s changes by a small amount, δs, the change in bending moment, $\delta(-G.d\psi/ds)$, is equal to the change in the moment of the overhanging weight, $ws. \cos \psi. \delta s$, which gives immediately the second differential intrinsic equation of the strip:

$$d^2\psi/ds^2 = -s. \cos \psi/S. \quad \text{.......... 1c}$$

This expression applies to many forms of "elastica" traced by strips under their own weight, a hoop being another instance. It is not integrable as a known function. An attempt was made to expand it as a power series, but the few terms obtained diminished so slowly that recourse was had to the empirical method when the stiffness test was first worked out. Hummel and Morton,[1] however, performed the laborious computation of a series of values that put our formula on a more satisfactory basis. A plot of their figures shows that for satisfactory accuracy more terms are necessary in the expansion, but a smooth curve is drawn through the more consistent later values (see below) by the formula adopted here:

$$S = l^3. \cos 0{\cdot}5\, \theta/8 \tan \theta \quad \text{.......... 1}$$

These authors use a different practical approximation: in our notation, that

$$S = 32d^3/\, 81\psi^4_0 \quad \text{.......... 1d}$$

where ψ_0 is the end slope: also that $S = d^3$ when $\psi_0 = 45°$. The end slope is, however, quite unsuitable for the measurement of the bending of fabric, with its curls and kinks. Nor is the rigorous series expansion, so far as it

*Those whose interest is mathematical may be warned that the analysis which follows is not an exercise in pure mathematics, but is intended to solve in a convenient manner the problems of testing fabric. It is sufficient for its purpose but no claim is made to new advances in the rigorous mathematical theory of elasticity. Rigour does not seem possible in taking account of the weight of the specimen, but where this is lacking, the results have been checked empirically. The approach indicated on p. T409 by dimensional equations with constants determined empirically, would be the least objectionable, but with the material and resources available it was neither accurate nor convenient enough to suffice by itself. A referee has pointed out that the relations for loaded beams might have been deduced at less length from the treatment given in paragraph 97 of Greenhill's *Elliptic Functions*.

has been evaluated, as satisfactory as our trigonometrical approximation, as may be seen from the following comparison of the ratios to $l^3/8 \tan\theta$ of the values of S obtained by the two methods. These ratios are the factor of correction to the formula for infinitesimal bending, and it will be seen that the values obtained by the series are still insufficient approximations, showing an upward trend at the beginning.

θ =	0°	3° 47′	7° 31′	11° 16′	15° 4′	18° 53′	22° 38′	26° 31′	30° 25′	34° 20′
Series	1·0	1·010	1·001	0·996	0·985	0·981	0·965	0·953	0·937	0·920
Formula	1·0	0·999	0·996	0·991	0·985	0·976	0·966	0·954	0·940	0·924

Peterson and Dantzig[4] have more recently given another treatment of this case. Deriving the same series expansion, they use only the first two terms, and transform it into a polar equation.

$$S = r^3 \,.\, \frac{\cos 4/3\,\theta}{8\,\theta} \qquad \text{1e}$$

Evidently this cannot be as accurate as the more complete evaluation of the series given by Hummel and Morton, but comparative figures cannot be given without working out the relation between r and l.

(2) Rectangle Weighted at end

This case is also figured by Fig. 8, if the weight W is shown acting at the end point A. This was solved, before the treatment of Hummel and Morton was seen, in a manner similar to that used by Lamb[2] for capillary curves.

The differential equation of the strip is

$$Gb.d\psi/ds = -W(X-x) \qquad \text{2a}$$

where b is the width. Substituting $-dx/\cos\psi = ds$ and integrating,

$$(1 - x/X)^2 = 1 - 2Gb/WX^2 . \sin\psi$$

or $v^2 = 2B^2(\cos\beta - \cos\psi') = 4B^2(\cos^2\beta/2 - \cos^2\psi'/2)$

where $B^2 = Gb/WX^2,\ \cos\beta = WX^2/2Gb,\ \psi' = \psi - \pi/2,\ v = 1 - x/X$

Therefore $v = 2Bk.\ \cos\phi \qquad \text{2b}$

where $k = \cos\beta/2,\ \cos\psi'/2 = k\sin\phi.$

Also $du/d\phi = du/dv.dv/d\phi$, where $u = y/X - C_1$, C_1 a constant.

$$= -\cot\psi'.2Bk\sin\phi = -B\cos\psi'/\sin\psi'/2$$

$$= B\{2\Delta(k,\phi) - 1/\Delta(k,\phi)\}$$

where $\Delta(k,\phi) = \sqrt{1 - k^2\sin^2\phi} = \sin\psi'/2.$

Hence, in the ordinary symbolism of elliptic functions,

$$u = 2B.E(k,\phi) - B.F(k,\phi) \qquad \text{2c}$$

$$v = 2k.B.\cos\phi.$$

To express Gb/W in terms of l and $\tan\theta$ (or Y/X), we take arbitrary values of $\sin^{-1} k$ and calculate the following quantities in order:

$$B^2 = 1/(4k^2 - 2),\ \phi_0 = \sin^{-1} 1/\sqrt{2k},$$

$$l/X = B\{F(k,\pi/2) - F(k,\phi_0)\},$$

$$-Y/X = l/X - 2B\{E(k,\pi/2) - E(k,\phi_0)\},$$

and $Gb/Wl^2 = B^2/(l/X)^2.$

Plotting the last two quantities against each other gives the required relation.

The familiar relation for infinitesimal bending can be expressed in the form—

$$Gb = Wl^2/3 \tan \theta \quad \text{.......... 2d}$$

A comparison of this equation with that derived above results in the application of a correcting factor, cos 0·93 θ, to Equation 2d. This provides a practically exact representation of the rigorous relation over the whole range. The values obtained for Gb/Wl^2 by the three formulæ, (a) the usual form for infinitesimal bending, (b) the corrected formula adopted, (c) the rigorous analysis, are as follows—

θ	0	6° 40′	13° 03′	20° 09′	34° 14′	49° 40′	58° 53′	90°
(a)	0	2·872	1·483	0·979	0·613	0·456	0·422	0·333
(b)	0	2·835	1·406	0·860	0·416	0·196	0·116	0
(c)	0	2·834	1·408	0·860	0·417	0·197	0·115	0

When the bending due to the weight of the strip itself is neglected, the formula adopted is therefore

$$S = \frac{W}{wb} \cdot \frac{l^2 \cos 0{\cdot}93\,\theta}{3 \tan \theta} \quad \text{.......... 2e}$$

To allow for the weight of the strip, Equation 1 may be expressed in the form 2d if W is replaced by $\frac{3wbl}{8} \cdot \frac{\cos 0{\cdot}5\,\theta}{\cos 0{\cdot}93\,\theta}$, which roughly represents the effective addition to the end load. For our present purposes, the varying term in θ may be replaced by its value at 20°, and the formula for the combined effect is

$$S = l^3 \left(\frac{\cos 0{\cdot}93\,\theta}{\tan \theta}\right) \left(\frac{W}{3wbl} + 0{\cdot}13)\right) \quad \text{.......... 2}$$

(3) Triangle Bending under its own Weight

The equation of moments in this case gives

$$\frac{d}{ds}\left(s\frac{d\psi}{ds}\right) = s\frac{d^2\psi}{ds^2} + \frac{d\psi}{ds} = -\frac{s^2}{2S}\cos\psi \quad \text{.......... 3a}$$

By the usual approximations, the equation for infinitesimal strain is easily obtained as

$$S = l^3/24 \tan \theta. \quad \text{.......... 3b}$$

The unsimplified differential equation for large bending can only be integrated by series expansion. Let $t = s^3/S$, then equation 3a reduces immediately to the form—

$$d/dt\,(t.d\psi/dt) = -\cos\psi,$$

the solution of which as an intrinsic equation has been obtained in the form—

$$\psi = a - t.\cos a - t^2.\sin 2a/8 + t^3(5\cos a + 3\cos 3a)/144 +$$
$$t^4(9\sin 4a + 16\sin 2a)/2304 + \quad \text{.......... 3c}$$

From the first four terms a relation has to be found between l^3/S and $\tan\theta$. Much labour is saved by doing this for several values of a, the end value of ψ, sufficient to determine the correction to the simple formula 3b.

With a fixed value of a, say 30°, a table is computed of ψ against t. Sin ψ and cos ψ are then plotted against $t^{\frac{1}{3}}$ and integrated by area from t=0 to ψ=0. The ratio of the two areas is the value of tan θ for the given

value of end slope. The corresponding value of t_0 is found by substituting $\psi=0$ in Equation 3c, and the reciprocal of this value equals S/l^3. In this way, the following values were found—

For $a=30°$,	$\tan\theta$ 0·4178,	$\theta=22° 40'$,	$S/l^3=0{\cdot}0973$,	$\cos m\theta=0{\cdot}9755$
45°	0·6881	34° 32′	0·0579	0·9560

To obtain our usual trigonometrical approximation, S/l^3 is multiplied by $24 \tan\theta$ to find the value of the correcting factor, $\cos m\theta$, as given above—hence the value of m. In the two examples given above, m was 0·56 and 0·49, and the round figure 0·5 gives S in terms of l^3 and $\tan\theta$ to within 0·5% (the values of $\cos 0{\cdot}5\,\theta\,/\,24 \tan\theta$ being 0·0978 and 0·0578). The formula adopted is therefore

$$S = l^3/\,3\,.\cos 0{\cdot}5\,\theta\,/\,8 \tan\theta \qquad \ldots\ldots 3$$

The same table suffices for this case as for case 1. It is legitimate to assume that the large bending of a uniform unweighted lamina of any shape, at least of those intermediate between a triangle and a rectangle, may similarly be described by the equation for infinitesimal bending modified by the correcting factor $\cos\theta/2$. The equation of a cantilever of any shape—rectangle, semi-circle, semi-ellipse, trapezium, triangle—would be obtained by multiplying the right hand side of Equation 1 by a numerical factor calculated for infinitesimal bending.

For a material of known stiffness, the rigorous theoretical deflection of a triangle of given length can be found from the series 3c. Substitute l^3/S for t, put $\psi=0$, and evaluate a by successive approximation: then proceed as above to find $\tan\theta$.

(4) Triangle Weighted at end

The bending moment at any point, $G.b/l.s.\ d\psi/ds = -Wx$. Differentiating, we have

$$\frac{s.d^2\psi}{ds^2} + \frac{d\psi}{ds} = -\frac{Wl}{Gb}.\cos\psi \qquad \ldots\ldots 4a$$

This must be integrated by series and the terms converge very slowly.

For infinitesimal strains, the radius of curvature is constant and equal to Gb/Wl, where b is the base, l the length of the triangle. From this the equation is obtained

$$G/W = l^2/2b.\tan\theta.$$

From the distribution of curvature, it was judged that the value of m in the correcting term should be if anything greater than for loaded rectangles (0·93), and there can be little error in taking it as unity. Allowing for the weight of the strip, as in case 2 the tentative formula is obtained—

$$S = l^3.\frac{\cos\theta}{\tan\theta}\left(\frac{W}{2wbl} + 0{\cdot}044\right) \qquad \ldots\ldots 4$$

The case has possible utility in testing materials that are stiff as well as curly.

(5) Segment of Circle Bending under its own Weight

This case is applicable only to the new broad form of tester, but is of special value for specimens that tend to curl; it also has the advantage that the stiffness in any direction can be measured on the one specimen. The symbols of Fig. 8 still apply. In addition, let r be the radius of the circle,

z the length of the semi-chord through P, ω the angle subtended by it. The bending moment at P is $-G.2z.d\psi/ds$, and the differential equation

$$d/ds.-2Gz.d\psi/ds=w.\cos\psi.r^2(\omega-\sin\omega.\cos\omega) \quad \text{...........5a}$$

This reduces to the form

$$d^2\psi/d\omega^2=-\frac{r^3}{2S}.\sin\omega(\omega-\sin\omega.\cos\omega).\cos\psi \quad \text{...........5b}$$

A first attempt at series expansion did not promise well, so recourse was had to the conclusions arrived at from case 3. Assuming infinitesimal strain, the bending moment at P due to the overhanging weight is

$$w.\int_A^P A.dx \text{ or } w\int_A^P (x-\mathrm{OP}).dA.$$

where x is the distance along OA and A the area beyond that distance. Either form integrates easily to give the equation:

$$G.2z.d^2y/dx^2=-wr^3(-\omega\cos\omega+\sin\omega-1/3\sin^3\omega) \quad \text{.........5c}$$

By the use of the relation $dx=r.\sin\omega.d\omega$, this equation is integrated twice without difficulty, giving the equations for a segment overhanging from a chord that subtends the angle 2Ω.

$$2S.dy/dx=-r^3\left[C_1-\omega\sin\omega-\frac{5}{3}\cos\omega-\frac{1}{9}\cos^3\omega\right],$$

where $$C'=\Omega\sin\Omega+\frac{5}{3}\cos\Omega+\frac{1}{9}\cos^3\Omega$$

and $$2S.y=r^4\left[C_1\cos\omega+\frac{\omega^2}{4}-\frac{\omega}{2}\cos\omega\sin\omega+\frac{10}{9}-\frac{13}{12}\cos^2\omega-\frac{1}{36}\cos^4\omega\right]_\Omega^\omega \quad 5e$$

In laborious but obvious steps, this leads to the expression

$$S=f(\Omega).l^3/8\tan\theta \quad \text{...5f}$$

where $$f(\Omega)=\left(40-2\cos\Omega+\cos^2\Omega-3\cos^3\Omega+9\Omega.\frac{\Omega-\sin 2\Omega}{1-\cos\Omega}\right)\Big/ 9\,(1-\cos\Omega)^3$$

and $\cos\Omega=1-l/r$, l being as usual the length overhanging.

As a segment is intermediate in form between a rectangle and a triangle, it is legitimate to assume the same correcting factor that proved suitable in both these cases for transforming the equation of infinitesimal to that of finite bending. Thus—

$$S=f(\Omega).l^3\cos 0{\cdot}5\,\theta/8\tan\theta \quad \text{...5}$$

For a semi-circle, the value of $f(\Omega)$ is 0·62866. To reduce observations to the quantity c, a table is given on p. T400 of the values of $f^{\frac{1}{3}}(\Omega)$ as $f(l/r)$.

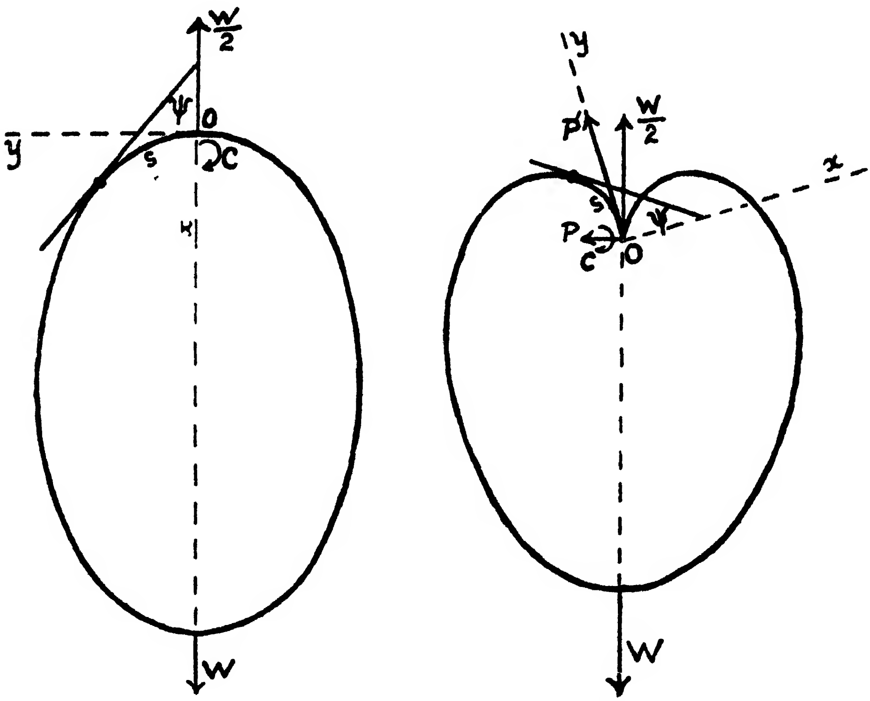
(6) Bending "Pear"

The two ends of a strip are brought together and secured between the platform and weight of the stiffness tester, and the pear-shaped loop so formed is allowed to overhang. The differential equation for this case could not be integrated, by series or otherwise, so there is no purpose in reproducing it. The necessary equation was obtained by a purely empirical method. Loops of feeler steel, of various lengths and thicknesses, were observed in this form, and the deflection of the mid-point was compared with

that observed by the simple cantilever method. It was found that the function $L^3/\tan\theta$ remained sensibly constant, and that the stiffness was given by the formula

$$S = l^3{}_0/\,8\tan\theta,$$

where l_0, the undistorted length of the loop, is equal to 0·4243 L, the circumference of the loop, from the analysis given on p. T414. The relation has been checked on paper and fabrics, and is sufficiently accurate and well established for the purposes of practical measurement.



(*a*) Ring (*b*) Heart

FIG 9

Hanging loops

The loops are drawn to the shape calculated for $k = \sin 80°$.

(7) Hanging Loops

Materials with a bending length of less than some 2 cms. are too soft to be tested satisfactorily by any cantilever method, in which the maximum amount of bending is 90°. By enforcing a much greater bending, more resistance may be developed, and its effects may be made measurable even with specimens of the softest knitted fabric. If the two ends of a weightless, elastic strip are held in grips closer together than the length of the strip, it takes a form in which the curvature at any point is proportional to the moment of the end constraints, and which is called an "elastica." A strip of perfectly flexible, heavy material, a chain, similarly constrained, takes another form in which the tangent of the angle that the tangent of the curve makes with the horizontal is proportional to the arc measured from the

lowest point, and which is called a "catenary." An actual strip of any material, which has in general both flexural rigidity and weight, takes an intermediate form from which the ratio of these two quantities can be deduced.

If the two ends of the strip are brought into contact, a loop is formed, the length of which, when allowed to hang straight downwards from the grip, is a sensitive measure of the ratio, G/w. Three loops of this kind have been studied, where one end has been brought against the other by bending through angles of 180° (pear), 360° (ring), and 540° (heart) (Fig. 9). Let l_0 be the length, from grip to lowest point, of the elastica of circumference L and d the depression caused by the weight. Then it may be seen from dimensional considerations that the value of d depends only on $S=G/w$ and L, and that the relation should be expressible in the form—

$$S = L^3 / f(d/L) \qquad \text{.......... 7a}$$

The value of d/L is limited between 0 for $S=\infty$ to the value given by a catenary, $D/L=0{\cdot}5-l_c/L$ when $S=0$. A suitable manner of expressing the strain is therefore in terms of $\tan\theta$ where $\theta=\frac{\pi}{2}\cdot\frac{d}{D}$. The relations for the several loops have been evaluated by analysis and by observations on feeler steel. Rigorous analysis of the form of a ring distorted by its own weight proved very intractable. Some rigour, but apparently no significant accuracy was sacrificed by solving the problem in the following manner. Relations were obtained for the length of a loop, of negligible weight, distorted by a weight W hung from the lowest point. Both for the ring and heart, these can be very satisfactorily expressed by the simple formula—

$$G/W = k.\,L^3.\cos\theta \,/\, \tan\theta \qquad \text{.......... 7b}$$

Equilibrium means a state of minimum potential energy, so that a minute displacement involves no change of energy, i.e. the drop of the weight represents the same amount of energy as the additional strain in the strip. Now, in a ring distorted by a weight, the centre of gravity of the strip is half the length of the loop below the grip, and moves half as far as the weight when an additional distortion is imposed. The effect of the weight of the strip may therefore be allowed for by an addition of $wL/2$ to the hanging weight W; or, if no weight is suspended, by substituting $wL/2$ for W, giving the relation—

$$S = G/w = k.\,L^3\cos\theta \,/\, \tan\theta \qquad \text{.......... 7}$$

The lack of rigour in this derivation lies in the fact that the form of a ring distorted by its own weight is somewhat different from that produced by a concentrated added weight. The latter is symmetrical about the horizontal axis, the former has a greater curvature at the top. On this account the centre of gravity moves rather more than half the change in length of the loop. On the other hand, the strain energy increases rather more for the same length change, so that the equivalence of $wL/2$ to W should not be greatly affected. The empirical check serves to confirm this.

The same device was used to derive the equation for a heart-shaped loop. Taken over the full range from elastica to catenary, the centre of gravity moves at a rate 0·652 of the change in length, and W is replaced by 0·652 wL. In Fig. 10 the analytical relations are compared with those observed for strips of feeler steel, of various length and thicknesses. The latter are subject to the errors of measurement of both the loop and cantilever methods,

including variations from uniformity and straightness in the strips, and deviate as much from each other as from the analytical relation. The value thus obtained for k in Equation 7 is not appreciably different from that

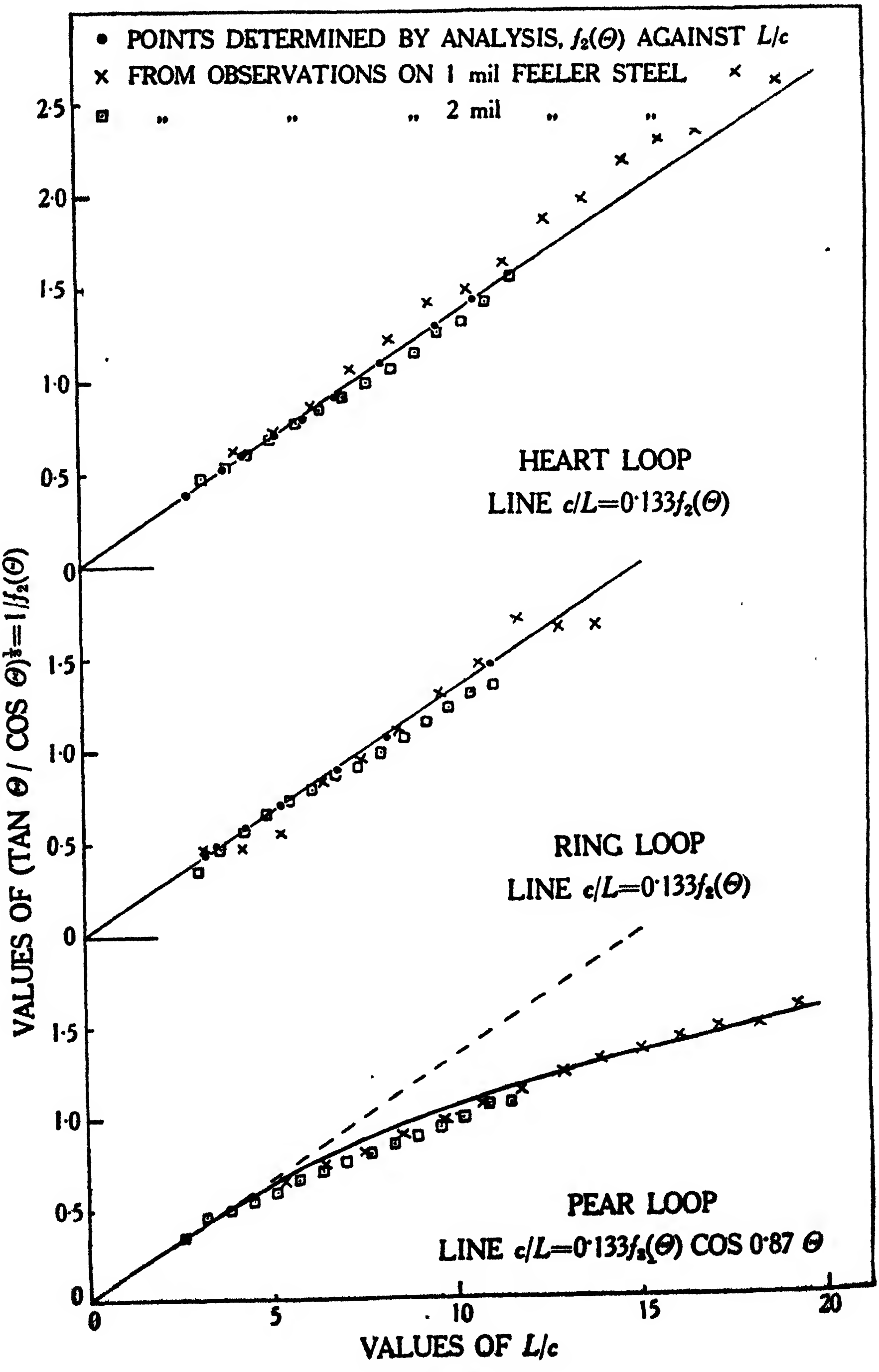


FIG. 10

obtained analytically, and may be fixed at 0·133. Equation 7 is then accurate within the accuracy obtainable with feeler steel, which gives more reproducible and regular results than any other material observed.

As far as present experience goes, the heart loop is of most value as a means of extending measurement of stiffness to the softest fabrics, while the ring offers the most promise for the measurement of yarn stiffness. The pear loop is less sensitive, and has not been so fully analysed, but the empirical relation has been observed for feeler steel and is also shown in Fig. 10. Over a range of small distortions it would appear that the same relation held as for the other two forms, but when L/c exceeds 4, the value of θ falls below that given by Equation 7. In this form of loop the weight of the strip is much less effective than a suspended weight, particularly in bending the bottom of the loop when it approaches the catenary form. The observations on the pear loop indicate that a similar deviation from Equation 7 may be expected of the other loops at extreme values of L/c. If so, they are fortunately inappreciable over the range of practical utility, for the observations of the heart loop follow the relation to the highest value of L/c observed, which is nearly 20. It is quite possible to form a loop of soft material with 5 cms. or less, when this value of L/c corresponds to a bending length of 0·25 cm., much less than any value yet observed.

Throughout the mathematical analysis it has been assumed that the bending moment is proportional to the curvature. The question of time effects must be considered separately, but even when Hooke's law is obeyed the ratio of moment to curvature increases when the latter becomes excessive. Such considerations, however, need hardly concern us in the measurement of quality.

(8) Analysis of the Ring Loop

The symbols shown in Fig. 9 being used, the equation of moments for a ring distorted by its own weight gives—

$$\delta.G\frac{d\psi}{ds} = -\delta C + \delta\frac{wL}{2}y - \delta s.\sin\psi.ws$$

which can be reduced to the form—

$$B\frac{d^2\psi'}{du^2} = -u\cos\psi' \qquad \text{.......................................8a}$$

where $\psi' = \psi + \pi/2$, $u = 1 - 2S/L$, and $B = 8G/wL^2$.

From this equation ψ' was expressed in a series of powers of u, but not in a form sufficiently convergent to give reasonable accuracy.

The intrinsic differential equation of a ring distorted by a suspended weight W is—

$$-G\frac{d\psi}{ds} = C - \frac{W}{2}y \qquad \text{..8b}$$

Substituting $dy/\sin\psi$ for ds and integrating

$$(c-y)^2 = c^2 - 2b^2\cos\psi = \frac{4b^2}{k^2}(1 - k^2\sin^2\varepsilon)$$

where $c = 2C/W$, $b^2 = 2G/W$, $k = 2b/\sqrt{c^2+2b^2}$, and $\varepsilon = \pi/2 - \psi/2$,

or $$y = \frac{2b}{k}\left(\sqrt{1-k^2/2} - \sqrt{1-k^2\sin^2\varepsilon}\right) \qquad \text{.......................8c}$$

Also $\frac{dx}{d\varepsilon}=\cot\psi\,.\,\frac{dy}{d\varepsilon}=-\frac{2b}{k}\,.\,\frac{k^2\cos 2\varepsilon}{2\sqrt{1-k^2\sin^2\varepsilon}}$

and $x=\frac{2b}{k}\left[(1-k^2/2)(F-F_0)-(E-E_0)\right]$ 8d

where $F=F(k.\varepsilon)$, $F_0=F(k,\pi/4)$, etc., standard elliptic functions.

Also $-b^2\,.\,\frac{d\psi}{ds}=(c-y)=\frac{2b}{k}\sqrt{1-k^2\sin^2\varepsilon}$

and $s=bk(F-F_0)$ 8e

When the end values $x=X$, $\varepsilon=\frac{3\pi}{4}$, and $s=L/2$ are substituted in 8d and 8e, the relation between the elongation of the ring and G/W is obtained in the form—

$$\frac{b}{L}=\frac{1}{4k(F_1-F_0)}$$

$$\frac{X-X_0}{L}=\frac{(F_1-F_0)-(E_1-E_0)}{k^2(F_1-F_0)}-0{\cdot}81831 \quad \text{..............8f}$$

For the relation between elongation and G/w in a ring bending under its own weight, $wL/2$ is substituted for W, when $c/L=(b/2L)^{\frac{2}{3}}$. The extreme limits of X are from L/π to $L/2$. and the elongation is expressed in terms of $\theta=90°(X-X_0)/0{\cdot}18169\,L$. A series of values of k being substituted, the following points were determined—

$\sin^{-1}k$	45°	50°	60°	70°	80°	85°	89°
L/c	3·232	3·571	4·341	5·332	6·851	8·210	10·988
θ	4·790	6·351	10·845	18·076	31·031	42·237	58·228

These points are plotted in Fig. 10 as $(\tan\theta/\cos\theta)^{\frac{1}{3}}$ against L/c, and compared with observations on feeler steel of 1 and 2 mil thickness. For these, θ is the value observed for rings of circumference L, c is derived from observations by the standard cantilever method.

Two problems are solved by this analysis, though the second does not concern the present subject. The stiffness of a ring distorted by its own weight is given by—

$$c/L=0{\cdot}133\,(\cos\theta/\tan\theta)^{\frac{1}{3}},$$

and, when a ring is used as a spring or as a structural member, the relation between its elongation and load is given by —

$$\tan\theta/W\cos\theta=0{\cdot}0047\,L^2/G. \quad \text{..........................8g}$$

NOTE—The rigorous equation 8a can be solved in the form—
$U=\pi u+B(\pi u+\pi u.\cos\pi u-2\sin\pi u+A_1u+A_5u^5+A_7u^7+\quad.\ .\ .\ .\ .\ )$
where $A_1+A_5+A_7+\quad.\ .\ .\ .\ =0$. The series in u proves awkward. When it is ignored, a moderate approximation is given for slight distortion, but apparently not as good as that adopted.

(9) Analysis of Heart Loop

In a heart loop from which a weight W is suspended, the constraints at the grip on the left end of the strip, Fig. 9, may be expressed as a pressure upwards of $W/2$, horizontally leftwards of P and a clock-wise couple or bending moment C. The ordinate y' is measured parallel to the resultant, P', of the pressures, x' being measured upwards at right angles to y'.

The intrinsic differential equation of the loop is—

$$G\frac{d\psi'}{ds}=P'x'+C \quad \text{......................................9a}$$

Substituting $dx/\cos\psi'$ for ds, and integrating

$$(x'+c)^2 = c^2 - 2b^2\sin\alpha + 2b^2\sin\psi'$$
$$= 4\frac{b^2}{k^2}(1-k^2\sin^2\varepsilon),$$

where $b^2 = G/P'$, $c = C/P'$, $\alpha = \psi'_0$, the angle between P' and P, $2\varepsilon = \pi/2 - \psi'$, and $k = 2b/\sqrt{c^2 + 2b^2(1-\sin\alpha)}$.

or
$$x' = \frac{2b}{k}\left(\sqrt{1-k^2\sin^2\varepsilon} - \sqrt{1-k^2\sin^2\varepsilon_0}\right) = \frac{2b}{k}(\Delta - \Delta_0) \qquad \text{......9b}$$

Also
$$\frac{dy'}{d\varepsilon} = \tan\psi'\,\frac{dx'}{d\varepsilon} = -\frac{2b}{k}\cdot\frac{k^2\cos 2\varepsilon}{2\Delta}$$

and
$$y' = \frac{2b}{k}\left[(1-k^2/2)(F-F_0) - (E-E_0)\right] \qquad \text{..................9c}$$

Also
$$b^2\frac{d\psi'}{ds} = x' + c = \frac{2b}{k}\cdot\Delta$$

and
$$s = bk(F_0 - F) \qquad \text{..9d}$$

At the bottom of the loop $\psi = \frac{3\pi}{2} + \alpha$, and for convenience we shall write

$$\delta F = F\left(k, \frac{\pi}{4} - \frac{\alpha}{2}\right) - F\left(k, -\frac{\pi}{2} - \frac{\alpha}{2}\right),\ \delta E = E\left(k, \frac{\pi}{4} - \frac{\alpha}{2}\right) - E\left(k, -\frac{\pi}{2} - \frac{\alpha}{2}\right)$$
and $\delta\Delta = \Delta - \Delta_0$.

Substituting the value $s = L/2$, we obtain $2b/L = 1/(k\delta F)$, and the value $y = 0 = -x'\sin\alpha + y'\cos\alpha$ gives the relation between k and α as $\tan\alpha.\delta\Delta = (1-k^2/2)\delta F - \delta E$. From this, pairs of values must be obtained by successive approximations. Eight such pairs of values were determined, and a smooth curve was drawn giving the value of k for any value of α from 0 to 90°.

Substituting the end values in the equation, $-x = x'\cos\alpha + y'\sin\alpha$, and using the above expression for $\tan\alpha$,

$$\frac{X}{L} = \frac{\delta\Delta}{k^2\delta F\cos\alpha} \qquad \text{..9e}$$

Returning to the original value of b and α, $2G/W = b^2/\sin\alpha$,

or
$$WL^2/8G = k^2.\delta F^2.\sin\alpha \qquad \text{....................................9f}$$

These two equations, 9e and 9f, define the relation for a weighted loop. For a strip under its own weight alone, we must find the weight W that is equivalent to the distributed weight wL, by comparing the movements of the lowest point and the centre of gravity. The vertical position of the latter is given by

$$\bar{x} = \frac{2}{L}\int x\frac{bk}{\Delta}\,d\varepsilon \qquad \text{..9g}$$

It is possible by graphical methods to compare the two rates of movement at all values of α, but the simpler approximation has been adopted of comparing the total movements to get an average value for wL in terms of W. Equation 9g is easily integrated for the undistorted loop to give $\bar{x}/L = 0{\cdot}0112$, which increases to $0{\cdot}25\,L$ for the catenary, while the lowest point moves from $0{\cdot}1337\,L$ to $0{\cdot}5\,L$, whence $W = 0{\cdot}652\,wL$, and

$$L/c = 2{\cdot}306\,(k^2\delta F^2\sin\alpha)^{\frac{1}{3}} \qquad \text{..............................9h}$$

The results of the calculations from the above formulæ are shown in the following table and plotted in Fig. 10. They are again well expressed by the formula—

$$c/L = 0{\cdot}133\ (\cos\theta\ /\ \tan\theta)^{\frac{1}{2}}$$

As the constant is not significantly different from 0·1337, this may also be written: $c = l\ (\cos\theta/\tan\theta)^{\frac{1}{2}}$, though no theoretical significance is attached to this simplification. The observations on feeler steel are in excellent agreement with the analysis, as far as available tables allow the results of the latter to be calculated, and continue to follow the above formula to the greatest distortion observed, where θ is 77°.

Table VIII

a	$\sin^{-1} k$	L/c	X/L	θ
0°	66·5°	0	0·1337	0
12	65	2·826	1472	3·32°
20	64·3	—	—	—
30	64	3·848	1673	8·25
41·7	65	4·374	1832	12·16
45	65·7	—	—	—
57·3	70	5·260	2090	18·49
66·7	75	6·024	2320	24·19
73·7	80	6·896	2584	30·63
80·0	85	8·169	3026	41·50
83·6	88	9·643	3482	52·69
84·94	89	10·670	3685	57·68
90	90	∞	0·5000	90

(10) Analysis of Pear Loop

This form of loop may be analysed in the same manner as the heart loop, but it is unnecessary here to pursue the analysis so far, as the hanging pear does not seem to offer any special advantages. The loop has been used as a cantilever, and it also offers a convenient method for measuring the limit of flexibility, so the form of the undistorted loop will be demonstrated here.

The end restraints may be expressed as an inward pressure P and a couple C. Measuring y along the axis, x the half-width, and ψ the angle between the tangent and the normal to the axis—

$$G\frac{d\psi}{ds} = Py - C \qquad \text{10a}$$

and $$(y - c)^2 = c^2 - 2b^2\cos\psi,$$

where $c = C/P$ and $b^2 = G/P$. Substituting $\cos\beta = c^2/\,2b^2$ and $\cos\psi/2 = \cos\beta/2.\ \sin\phi = k\sin\phi$, this reduces to

$$y = 2kb(\cos\phi - \cos\phi_0) \qquad \text{10b}$$

Also $$\frac{dx}{d\phi} = \cot\psi\,\frac{dy}{d\phi} = -\frac{b\cos\psi}{\sin\psi/2}$$

and $$x = b(2E - F) \qquad \text{10c}$$

Also $$b^2 d\psi/ds = y - c = 2kb\cos\phi \qquad \text{10d}$$

whence $$s = b(F_0 - F). \qquad \text{10e}$$

When y is a maximum at the end of the loop, ϕ is zero, giving from 10*e*, $2b/L = 1/F_0$, and from 10*c*, $F_0 = F(k, \phi_0) = 2E_0$. From the last condition, the value of k is determined as $0{\cdot}8554 = \sin 58{\cdot}8°$, and ϕ_0 as 124·25°. Then b/L is 0·1587, and y (max.), the length of the loop, is 0·4243 L.

From the above equations the form of the loop was plotted for a circumference L of 20 inches, and the form was found identical with that of a loop of feeler steel.

(11) A Test for the Limit of Flexibility

From equation 10d, the radius of curvature at any point

$$R = ds/d\psi = L/10{\cdot}77 \cos \phi, \qquad \text{......11a}$$

and the radius of curvature at the end of the loop is $0{\cdot}093\ L$, the curvature being greatest at this point. This fact offers a convenient method for observing the effect of excessive bending on moderately brittle materials.

The test has been applied to starch film to measure the maximum strain when the specimen snaps. A strip is bent into pear shape, and the nip is moved forward to make the pear smaller and smaller till it snaps, when the circumference L is given by the position of the nip. The strain is very localised, and is a maximum in the outer skin at the end. To compare materials of different thicknesses, the strain may therefore be calculated as

$$\text{Maximum strain} = d/2R = 5{\cdot}385\ d/L \qquad \text{......11}$$

Among a series of starch films of varying composition (additions of waxes, etc.), the flexibility varied in rough agreement with the ultimate extensibility, but was consistently much higher. In the tensile test the extension is cut short by rupture of the weakest flaw, and the ultimate value observed is far below the real limit at which the material ruptures.

The same test may be used to test the cracking of varnished (electrical) or doped (aircraft) fabric, and may possibly be applied to stiff filled and calendered material.

(12) Stiffness in any Direction

A formula is given by Love[3] for the Young's modulus in any direction of a body with three planes of symmetry at right angles. Cloth may be treated as a lamina with two planes of symmetry and the Young's modulus in any direction in the plane, for which the third direction cosine is always zero, is given by —

$$1/E = l^4/E_1 + m^4/E_2 + 2l^2m^2/F_3.$$

E_1, E_2 and F_3 are given in terms of the co-ordinates of the strains in a very general strain energy-function but experimentally it appears that $F_3^2 = E_1.E_2$ and

$$1/E = (l^2/\sqrt{E_1} + m^2/\sqrt{E_2})^2$$

or, as w and d are not dependent on the direction,

$$1/S = (\cos^2 \alpha + k^2 \sin^2 \alpha)^2/S_w.$$

where α is the angle with the warp, S the value of S in the warp direction, $k^4 = S_w/S_e$.

The mean value of S in any direction $\overline{S}$

$$= \frac{2}{\pi}\int_0^{\frac{\pi}{2}} S.d\alpha$$

$$= \frac{2S\alpha}{\pi}\int_0^{\frac{\pi}{2}} \frac{(1+t^2).dt}{(k^2+t^2)^2} \quad \text{where } t = \tan\alpha$$

$$= \frac{2S\alpha}{\pi}\left[\frac{1}{k}\cdot\frac{k^2+1}{2k^2}.\tan^{-1}\frac{t}{k} + \frac{1-k^2}{2k^2}\cdot\frac{t}{t^2+k^2}\right]_{\theta=0}^{\theta=\frac{\pi}{2}}$$

reducing to $\overline{S} = \sqrt{S_w . S_e} . \frac{1}{2}(1/k + k)$.

The formulæ may be used also for G or for q as for S, and the formulæ for c are given immediately by substituting c^3 for S. They are, of course, not rigorous, for the "Young's Modulus" in different directions of a fabric is a quantity scarcely capable of exact definition, but the forms suggested by the theory of homogeneous material are found to be satisfactory empirically.

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27—THE WEIGHT PER INCH OF FIBRES OF DIFFERENT LENGTHS AND THE NUMBERS OF FIBRES OF DIFFERENT LENGTHS PER SEED, FOR EACH OF THE STANDARD INDIAN COTTONS

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SUMMARY

The object of the investigation has been to determine the values of the fibre-weight per unit length for different lengths of fibre of a given cotton, with a view to ascertaining whether any differences therein affect the value of the mean fibre-weight as determined by the ordinary cutting method, in which any such differences are ignored. The work has been extended so as to make possible the calculation of the average number of fibres per seed for each cotton.

The material for investigation consisted of 18 standard Indian cottons and five American cottons. The seed-weight and lint-weight per seed were determined for a weighed amount of *kapas* (seed-cotton) of each Indian cotton; the ginning percentage was then calculated; the lint was used for the determination of the percentage distribution of length by the Balls sorter, and for the determination of the fibre-weight per centimetre as follows—By means of the Baer sorter, fibres of different lengths were grouped together, the centimetre-lengths were cut from each group, and the fibre-weight per centimetre was determined for each group-length. From these tests the following conclusions are drawn—

(1) It cannot be accepted as universally true that the fibre-weight per unit length is the same for different lengths of fibre of a given cotton.

(2) For the *hirsutum* cottons, the fibres of longer lengths of a given cotton generally have less fibre-weight per inch.

(3) The *herbaceum, neglectum*, and *indicum* cottons do not generally show any large change of fibre-weight with fibre-length; the chief exceptions are Aligarh A. 19 and Mollisoni, both of which have in each season a much less fibre-weight in the longer lengths.

(4) In spite of the variation of fibre-weight with fibre-length in some cases, the effect upon the mean fibre-weight is not sufficient to make this essentially different from the value obtained by the ordinary cutting method, in which any such variation is ignored. But there still remains the possibility that the cutting method may give rise to erroneous results owing to the variation of fibre-weight along the length of a single fibre.

(5) The number of fibres per seed may differ greatly for different species, for different varieties of the same species, or for the same variety in different seasons.

(6) For a series of cottons differing from one another not only in their conditions of growth, but also in variety and species, there is no direct proportionality between the number of fibres per seed and (1) the lint index, or (2) the ratio of the lint-weight per seed to the seed-weight, or (3) the ginning percentage.

I—INTRODUCTION

A previous paper by one of us[1a] contains a discussion of the methods of determination of unit fibre-weight, i.e. the average weight of a single fibre of a given cotton. It is there pointed out that Leake's[3] method of weighing whole fibres is unimpeachable so long as the sampling is accurate, but that the method introduced by Balls[4], and adopted with modifications both by Burd[6] and Morton[7a], of cutting a standard length out of the middle portions of selected fibres, and weighing a given number of the cut-out lengths, is open to two objections—first, that it necessarily entails a biassed selection of fibres, for the fibres selected for cutting must be appreciably longer than the standard length which is cut out; and secondly, that any cut-out length must necessarily be the middle portion of the fibre, and this may not be representative of the whole length.

Both Balls[5] and Morton[7a] consider the first objection to be of little weight, because they each found that in a sample of Sakel cotton there was no appreciable difference of fibre-weight per inch for different lengths of fibre. But, as pointed out in the previous paper, there are reasonable grounds for apprehending that the result for Sakel is not general for all cottons, and some preliminary results were quoted which seemed to justify the apprehension. The present paper represents in the main an extended investigation of how far the first objection applies to the use of the cutting method for determining the unit fibre-weight of Indian cottons. A parallel investigation of the second objection will form the subject of another paper.

The lint required for the present investigation was obtained directly from seed-cotton by removing the lint by hand; a slight extension of the work provided the means of further testing certain generalisations concerning ginning percentage and lint index, discussed in the previous paper[1b], and, in addition, it enabled a calculation to be made of the average number of fibres of different lengths attached to each seed of each of the standard Indian cottons. For this purpose a sample of seed-cotton (*kapas*) selected at random was weighed, delinted by hand, and the lint and seed weighed separately. The lint was made into a sliver, and a determination of fibre-length made on part of this by the Balls sorter; the remaining portion of the sliver was placed across the combs of a Baer sorter, from which fibres of different length-intervals were removed separately, measured for length, and tested for fibre-weight by a cutting method. From the results obtained it was possible to calculate the ginning percentage, the lint-index, the unit fibre-weight for various lengths, and the average numbers of fibres of different lengths per seed.

Table I

List of Cottons Used

Cotton	Botanical Species	Place of Growth	Highest Standard Warp Counts
1. Dharwar 1	*G. herbaceum* ...	Bombay	34
2. Surat 1027 A.L.F. ...	,, ...	,, ...	32
3. Wagad 4	,, ...	,, ...	18
4. Wagad 8	,, ...	,, ...	16
5. Hagari 25	,, ...	Madras	30
6. Cawnpore K. 22	*G. neglectum* *G. arboreum*	United Provinces	14
7. Bundelkhand J.N. 1 ...	*G. neglectum* ...	,,	14
8. Aligarh A. 19	,, ...	,,	8
9. Mollisoni	*G. indicum* ...	Punjab	8
10. Umri Bani	,, ...	Hyderabad ...	24
11. Nandyal 14...	,, ...	Madras	34
12. Karunganni	,, ...	,, ...	26
13. Gadag 1	*G. hirsutum* ...	Bombay	38
14. P.A. 4F	,, ...	Punjab	24
15. P.A. 285F	,, ...	,, ...	34
16. P.A. 289F	,, ...	,, ...	40
17. Cawnpore-American C.A. 9	,, ...	United Provinces	40
18. Cambodia Co. 1	,, ...	Madras	38
Mississippi	*G. hirsutum* ...	U.S.A.	30
Memphis	,, ...	,, ...	40
Texas	,, ...	,, ...	30

II—MATERIALS AND METHODS

Material—The material used consisted of *kapas* (i.e. seed-cotton) of 18 standard Indian cottons, of both seasons 1926–27 and 1927–28, and the lint of five American cottons for which seed-cotton was not available. A list of the various cottons, full particulars of which are given in Technological Reports on Standard Indian Cottons, 1929[2a] are shown in Table I.

Sampling—About one pound-weight of *kapas* of each cotton was available; a rough calculation showed that only about one twenty-fifth of this was required for making a sliver for the Balls sorter, and the following procedure was therefore adopted for obtaining this fraction with a view to ensuring that it should be a representative sample—The pound-weight of *kapas* was well mixed by hand, and then divided into 10 approximately equal parts; each of these parts was sub-divided into five sub-groups, and each sub-group again sub-divided into a further five sub-groups. Thus each of the ten groups was made to yield 25 sub-groups, each containing from seven to 35 seeds, according to the particular variety of cotton under test; one sub-group out of the 25 was then chosen by lot, and the ten sub-groups thus obtained were mixed together to form the working sample. This method of sampling was adopted in preference to taking a number of seeds from each sub-group because it was felt that it would be difficult to avoid biassed judgment in extracting single seeds from a sub-group.

Ginning Percentage and Lint Index—From each working sample, groups of 20 seeds, with their adherent lint, were extracted successively until not more than 20 seeds remained, the remainder being also treated as a group. Each group was weighed, and then carefully delinted by hand, after which the total weight of the 20 seeds was determined, and of the lint removed from them. The number of groups varied from four for the heavy seeds of Cambodia Co. 1 to 16 for Nandyal 14. In general, the differences in weight between the groups of any one sample were quite small; exceptions were the two Punjab-American cottons, 4F and 289F, of 1926–27; each of these cottons gave 16 groups of seeds, and the maximum group-weights were four times and twice the minimum group-weights for the 4F and 289F respectively. As might be expected, the variation in ginning percentage was much less, the greatest variation being 10% in the case of the 4F just mentioned.

Fibre-length Distribution—The lint from the different groups of seeds was thoroughly mixed by hand, and made into a sliver by hand, tufts of fibres being successively selected at random for this purpose. The draw-box of the Balls sledge sorter was not employed, in order to minimise the risk of fibre-breakage. The hand-made sliver was used in the sledge sorter to determine the fibre-length distribution, and thence also the mean fibre-length. Ordinarily two determinations were made and found to give mutually consistent results for the distribution; but if the agreement between two determinations was not good, further determinations were made, and the mean of all the determinations was taken as representing approximately the true distribution. Thus any errors in the distributions given in the present paper cannot have been large.

Determination of Fibre-weight. (a) Cutting out one-centimetre lengths—In all essentials, Morton's method[7a] was used for the determination of the fibre-weight. First, however, it was necessary to arrange for the selection of the different lengths of fibre, so that these could be tested separately for their

fibre-weights; the method adopted was as follows—The remaining portion of the sliver of a given cotton used in the sledge sorter was placed across the combs of a Baer sorter, and the fibres extracted and rearranged so that they all had one end touching a common line at right angles to the lengths of the fibres, i.e. as is commonly done in the first operation of any Baer sorter test. The fibres falling in the longest group-length were then withdrawn by means of the nipper, and placed upon a piece of black paper covering a small square of linoleum; the average length of the fibres was ascertained with a pair of dividers and a scale. The fibres were stretched by clipping them at one end near the edge of the linoleum, using a spring clip for the purpose, and by pressing them down at the other end with a steel scale; centimetre lengths were then cut out from the middle parts of these fibres, by means of a cutter consisting of two safety-razor blades fixed parallel to each other one centimetre apart in a brass holder. The centimetre-lengths thus cut out were placed between two microscope glass slides held together by a spring clip. The fibres falling in the next longest group-length were next treated in a similar way and the centimetre-lengths cut out from them were placed between another pair of glass slides; and so on for fibres of all the different group-lengths, all the centimetre-lengths from fibres falling in any one group-length of a given sample being placed between a separate pair of glass slides, suitably labelled. Fibres falling in a group-length constituting less than 5% of the whole were not cut, as few fibres were thus available for the purpose, and moreover, neglecting them could cause but little error in the mean value for fibre-weight of the sample.

The centimetre-cutter could not be used for fibres falling in group-lengths less than $\frac{5}{8}$ inch, so that if an appreciable quantity of fibres fell within such group-lengths a "quarter-inch cutter" was employed for them instead. The distance between the blades was measured for each cutter by means of a travelling microscope; the mean values obtained were 9·958 mm. for the centimetre-cutter and 6·222 mm. for the quarter-inch cutter, representing errors of −0·45 and −2·0% respectively, for which corrections have been duly made in the results.

(*b*) *Fibre-weight*—In determining the fibre-weight for any group-length, fibres were removed from the appropriate pair of glass slides by means of ivory-tipped forceps, and counted into a folded strip of stiff blue paper. In the earlier experiments a constant number of fibres was taken for weighing, and their weight determined on a quartz fibre torsion micro-balance, of the type described by Morton.[76] This balance was calibrated by weighing on it some 50 small glass capillary tubes of varying size, whose absolute weights were determined on a Bunge micro-balance; the calibration was checked for every sample of cotton tested, by re-weighing on it each of three capillary tubes, of small, medium, and large size respectively. In many cases the fibre-weights were checked by direct weighing of the fibres in the Bunge micro-balance, and very good agreement was obtained between the readings on the two balances. In the later tests a null method was used, i.e. the total number of fibres taken for any one weighing was adjusted by trial so that approximately the same deflection was always caused in the beam of the quartz fibre torsion micro-balance used for the weighing; the standard deflection was that caused by a half-milligramme weight, whose correctness was checked from time to time by weighing in the Bunge micro-balance. The sensitiveness of the quartz fibre micro-balance was subject only to slight

variation; throughout a whole year the deflection for a half-milligramme weight remained between the limits of 19·0 and 20·5 divisions, day-to-day fluctuations being practically negligible.

For determining the fibre-weight no less than 20 groups of fibres were weighed for each group-length. But in order to eliminate any influence of humidity on the results, successive weighings were not made on the 20 groups from each group-length, but, instead, single groups from all the different group-lengths were weighed in turn, the process being repeated until all the 20 groups of each group-length had been weighed. Readings of the relative humidity were taken at intervals, and the mean relative humidity prevailing during the weighing was thus obtained for each sample. In order to make the weights for different samples more strictly comparable with one another, all the fibre-weights have been reduced to a common standard (70% relative humidity) by the application of the correction-factors of the table given in Technological Reports 1929[2b]—a table based upon the results of Urquhart and Williams[8] for an Indian cotton.

It should be noted that the cutting method only gives us the weight per unit length of the middle centimetre of the fibre, whereas what we desire to know is the weight per unit length of the whole fibre, and if we take the latter as being the same as for the middle centimetre some error may be caused, as already pointed out (page T417), especially when the apex of the fibre is much finer than the middle portions. In the latter case, more of the apical portion will be contained in the centimetre section of short group-lengths than of long group-lengths, so that if no other factor were operative we should expect a shorter group-length to have a lesser weight per centimetre according to the cutting method even though in actual fact the average fibre-weight per unit length for whole fibres of different lengths was the same.

Number of Fibres per Seed—If W is the average weight of lint per seed, and p is the percentage by weight of fibres falling within a given group-length (as obtained by means of the Balls sorter), then $\left(W \times \frac{p}{100}\right)$ evidently represents the weight of the fibres of that group-length on each seed; and if f is the unit fibre-weight (i.e. the average weight of a whole fibre) for that group-length, then $\frac{pW}{100f}$ gives us the number of fibres of that group-length per seed. We can perform the calculation for each group-length, and then add the numbers of fibres per seed of each group-length to obtain the total number of fibres per seed.

To apply this formula we need the average weight of a whole fibre for each group-length. In the calculation it has been assumed that the weight per unit length of the whole fibre is not sufficiently different from that of the middle centimetre to cause any appreciable error.

The procedure then is to apportion the total weight of lint per seed between the different group-lengths in accordance with the percentage of each present by weight, as shown by the Balls sorter results; the fibre-weight per centimetre for each group-length is multiplied by the mean group-length to give the average weight of a whole fibre of that group-length; and finally, the actual weight of lint of each group-length per seed is divided by the average weight of a whole fibre of that group-length—this gives the total number of fibres of that group-length per seed. Table II, taken from the previous paper,[1c] shows the method of calculation in detail for Nandyal 14—

Table II

Calculation of Number of Fibres per Seed of Nandyal 14
Weight of Lint per Seed = 14·4 milligrammes

Mean Group-length (Eighths of an Inch)	Percentage by Weight of each Group-length (Balls' Sorter)	Weight of Fibre of each Group-length per Seed (milligramme)	Fibre-weight per Inch for each Group-length (milligramme)	Fibre-weight per Whole Fibre for each Group-length (milligramme)	No. of Fibres of each Group-length per Seed
3	0·7	0·101	0·00348	0·00130	78
4	1·5	0·216	0·00348	0·00174	124
5	3·1	0·446	0·00348	0·00217	206
6	7·3	1·051	0·00348	0·00261	403
7	19·7	2·837	0·00389	0·00340	835
8	39·6	5·702	0·00398	0·00398	1,433
9	23·8	3·427	0·00396	0·00446	769
10	4·3	0·619	0·00389	0·00486	128

Total number of fibres per seed, 3,976.

As already remarked, the fibre-weight per inch was not determined for group-lengths of which the percentage present was less than 5%; in calculating the number of fibres of such group-lengths present on a seed, it has been assumed that their fibre-weight per inch is the same as that of the nearest group-length of which the fibre-weight has been determined.

III—DISCUSSION OF THE RESULTS

(1) The Weight per Inch of Fibres (of a Given Cotton) of Different Lengths

The results of the tests for these cottons are given in the Appendix, Tables I–V; they are shown graphically in Figs. 1–3. Some difficulty is encountered in deciding what differences between the results for the fibre-weights of different lengths are to be regarded as significant. Although some idea of the degree of significance may be obtained from the values of probable errors, yet in view of the small number of determinations in any particular case, too much stress cannot be laid on such values. Moreover, the probable error of a value obtained for the fibre-weight of a particular length is a measure only of the degree of variation within the sample actually taken for weighment, and this cannot be accepted as an indication also of the variation between samples of that particular length. At the same time it is desirable to have some quantitative measure of the degree of variation between the fibre-weights of the different lengths. In the discussion that follows it has been decided to confine attention to the maximum variation which occurs in these fibre-weights of different lengths. Now in many cases, the fibre-weights have been determined for six different fibre-lengths; and as the total possible number of different pairs that may be selected out of a set of six values is 15, it is on the maximum difference occurring between these 15 pairs that we are about to focus attention. It is evident that errors of sampling or experiment may easily occur sufficient to give a fairly large difference between one pair of values out of the 15. It has been decided therefore to regard any difference not exceeding 10% as one which might possibly be due to these errors of sampling or experiment. At the same time, even when the difference between one pair exceeds 10% it is not concluded that this is necessarily significant. Due regard is paid to the other values which are obtained for the other lengths of fibre, and if the large difference is found to be exceptional it is not accepted as conclusive evidence of the

existence of a real difference in fibre-weight between different fibre-lengths. It must be emphasised, however, that this negative attitude to all differences of fibre-weights not exceeding 10% does not preclude the possibility that the differences *are* real; they may be real, but we cannot definitely say that they are so. As a consequence, only those differences are accepted as real in which there is a great difference in fibre-weight between the least and the greatest; as a general rule, too, it is the value for the extreme lengths which have the extreme values of fibre-weight, the intermediate values of fibre-length having intermediate values for fibre-weight. Where such a gradation exists and where it is combined with large differences of fibre-weight for different fibre-lengths, it is impossible to resist the conclusion that these differences are real.

As it is to be expected that the variation of fibre-weight with fibre-length is more likely to be of the same order for cottons of the same species than for cottons grown in the same district, the cottons forming the subject of the present investigation have been grouped together according to the species to which they belong. The results for the *herbaceum* cottons are given in Table I (Appendix) and Fig. 1; these results are somewhat erratic, and in only one case is the evidence decisive of real differences between the fibre-weights of different lengths, viz. for Hagari 25, 1927–28; for this cotton the maximum variation is 18%, reckoned on the lower figure, the shorter length being the coarser, and fibres of intermediate length having intermediate weights. A somewhat similar result is given by Dharwar 1, 1927–28, but in this case the gradation is very small except between the lengths $1\frac{1}{8}$ to $1\frac{1}{4}$ inch. Surat 1027 A.L.F., 1927–28, also shows a similar gradation from the shortest to the longest length, but again the fall is greatest for fibre-lengths between $1\frac{1}{8}$ to $1\frac{1}{4}$ inch. The results for Wagad 4 both in 1926–27 and 1927–28 are of exceptional interest because of their clear indication that the longer length is also the coarser, both curves being of the ascending type with anomalous results for the fibre-lengths $\frac{1}{2}$ to $\frac{5}{8}$ inch; the reality of these differences must be regarded as rather doubtful, however, seeing that Wagad 8, a very closely related cotton, gives results which are quite different from those obtained for Wagad 4. In all other cases the differences for these five cottons in the two seasons are insignificant, and occasionally irregular also.

There are only two *neglectum* cottons, but K. 22, the hybrid between *G. neglectum* and *G. arboreum*, may be included under the same heading. The results for these cottons are given in Table II (Appendix) and Fig. 1. The three cottons exhibit in both seasons a general tendency for the shorter length to be coarser, though the differences for J.N. 1 and K. 22 must be regarded as of doubtful significance. But in the case of A. 19, the slope of the curve in both cases is so high that there can be but little doubt that in this case the short length really is much coarser than the longer length, and in 1927–28 the $\frac{1}{2}$-inch length has a fibre-weight per inch no less than 27% greater than that of the $\frac{7}{8}$ inch. This result is in agreement with the results obtained for single seeds of Aligarh A. 19 reported in the previous paper.[1d]

Four cottons are included in the *indicum* group, the results for which are given in Table III (Appendix) and Fig. 2. The results for the variation are insignificant, and in some cases irregular, for the three cottons Umri Bani, Nandyal 14, and Karunganni; but in the case of Mollisoni the fibre-weight per inch decreases rapidly as the fibre-length increases, the differences of fibre-weight for the $\frac{1}{2}$-inch and 1-inch lengths amounting to 21 and 33% for 1926–27

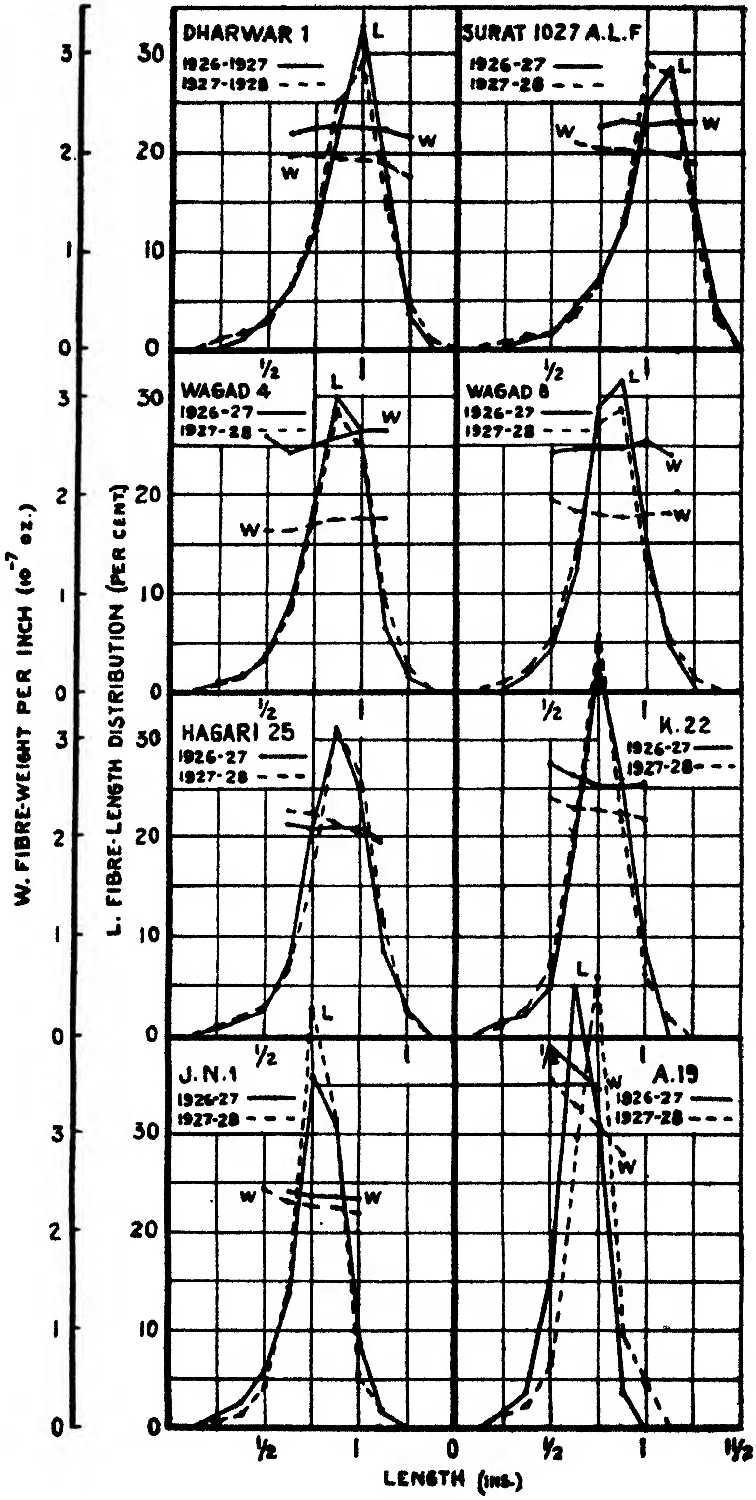
DHARWAR 1
1926-1927
1927-1928
SURAT 1027 A.L.F
1926-27
1927-28
WAGAD 4
1926-27
1927-28
WAGAD 8
1926-27
1927-28
HAGARI 25
1926-27
1927-28
K.22
1926-27
1927-28
J.N.1
1926-27
1927-28
A.19
1926-27
1927-28
L
W
W. FIBRE-WEIGHT PER INCH (10^{-7} oz.)
L. FIBRE-LENGTH DISTRIBUTION (PER CENT.)
LENGTH (INS.)
½
1
0
1½

Fig. 1.

and 1927–28—respectively. The curves for fibre-length distribution and change of fibre-weight with fibre-length of Mollisoni bear a striking resemblance to those of Aligarh A. 19. This suggests some relation between these two cottons; it is in fact doubtful whether Mollisoni should really be included in the *indicum* group and there are botanical reasons for considering that Mollisoni is not a pure *indicum*, but contains some of the features associated with *neglectum* cotton.

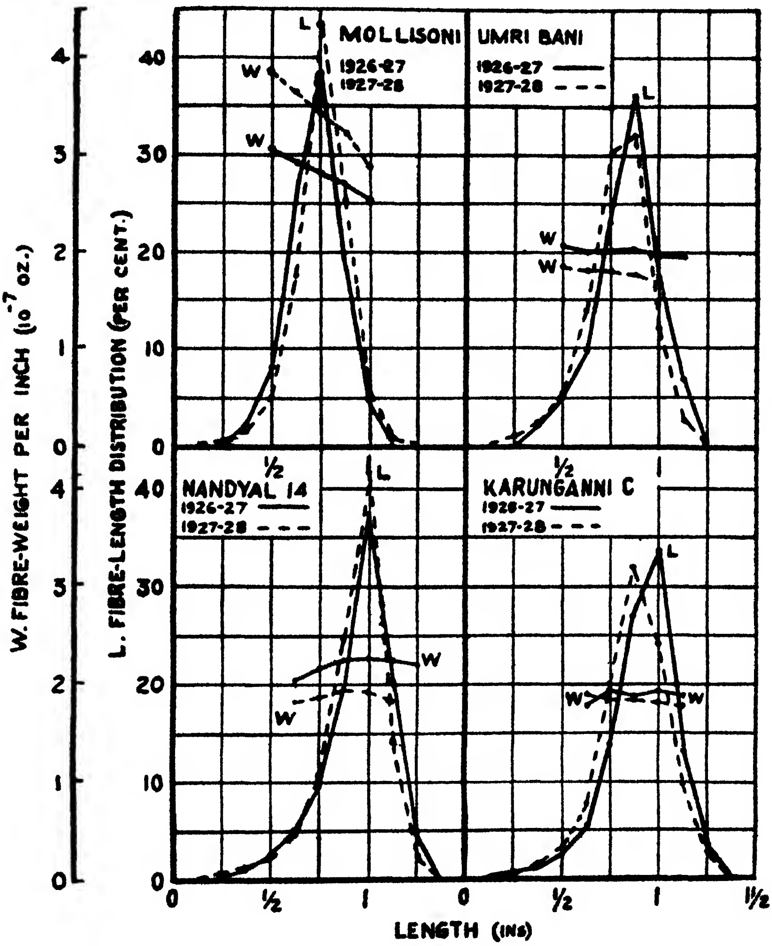

Fig. 2

The *hirsutum* group of cottons is the largest of those tested. It comprises six exotic Indian types grown in two seasons (Table IV, Appendix, and Fig. 3) and three types grown in the United States of America (Table V, Appendix, and Fig. 3), for one of which, Texas, samples of three different seasons have been tested. In general, the *hirsutum* cottons display the feature of decrease of fibre-weight per inch with increase of length; the feature is most marked in the cottons grown in America, and for these the variation in fibre-weight per inch between the shortest and longest lengths measured, is from 22% for

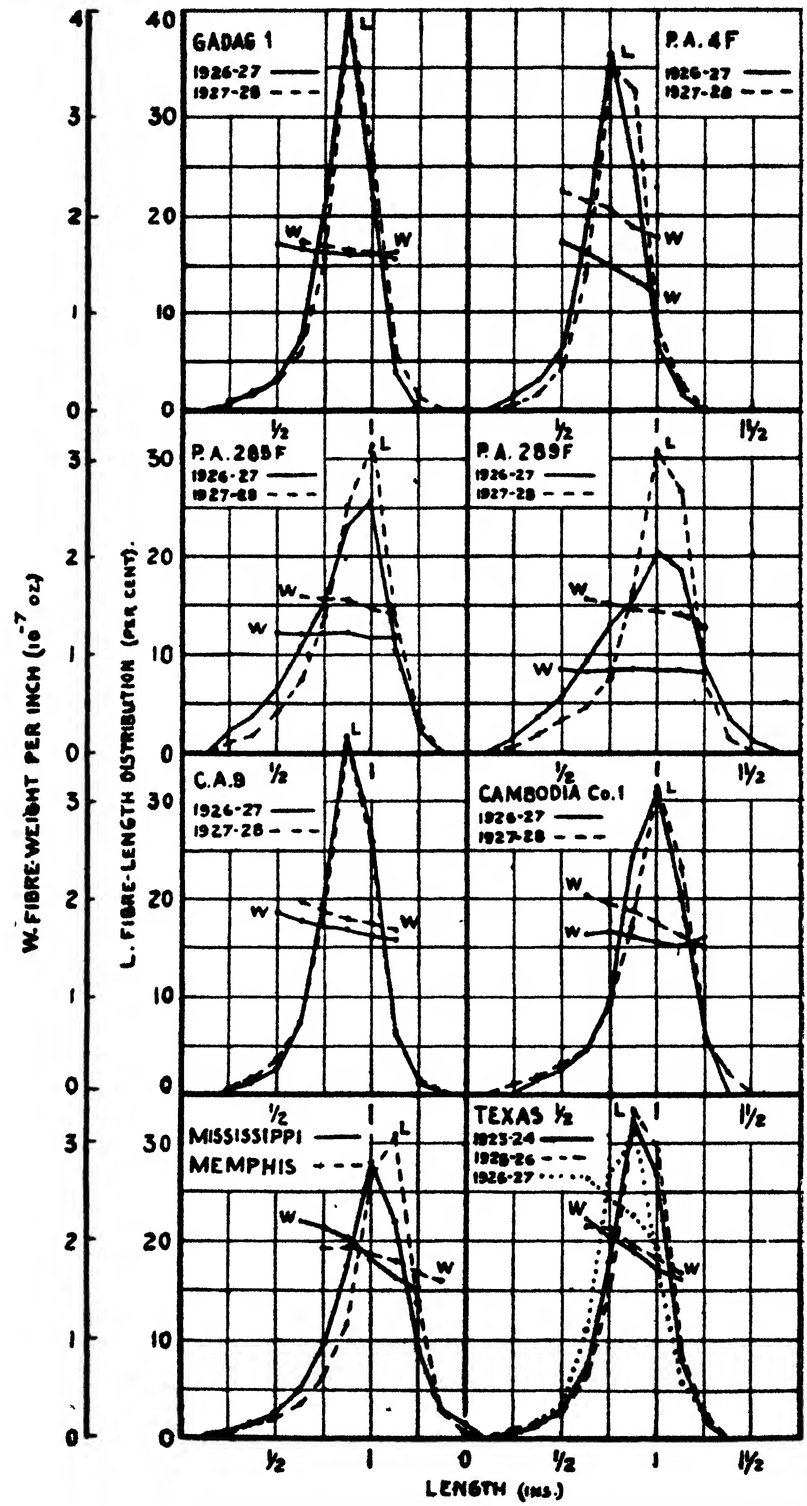
GADAG 1
1926-27
1927-28
P.A. 4F
1926-27
1927-28
P.A. 285F
1926-27
1927-28
P.A. 289F
1926-27
1927-28
C.A.9
1926-27
1927-28
CAMBODIA Co.1
1926-27
1927-28
MISSISSIPPI
MEMPHIS
TEXAS
1925-24
1925-26
1926-27
W. FIBRE-WEIGHT PER INCH (10⁻⁷ oz)
L. FIBRE-LENGTH DISTRIBUTION (PER CENT)
LENGTH (INS.)

Fig. 3

Memphis, 1925–26, to 45% for Mississippi, 1923–24. In all cases, the intermediate lengths have intermediate fibre-weights per inch. For these cottons, therefore, the variation must be regarded as real. For the *hirsutum* cottons grown in India, the variations are not on the whole so striking, and in some cases the variation is comparatively small, e.g. Gadag 1 in both seasons, and P.A. 285F in 1926–27.

If we now review the results for all the different samples we have the following results—

Of the *hirsutum* samples grown in India, eight out of 12 show a decreasing fibre-weight with increasing fibre-length.

Of the *hirsutum* samples grown in the United States of America, five out of five show a decreasing fibre-weight with increasing fibre-length.

Of the *herbaceum* samples one out of ten shows a decreasing fibre-weight with increasing fibre-length.

Of the *neglectum* and *indicum* samples, four out of 14 show a decreasing fibre-weight with increasing fibre-length.

In all, therefore, 18 samples out of 41 show a decreasing fibre-weight with increasing fibre-length. Even if the errors due to sampling and experiment may give differences as large as 10%, these results show that in some cases, at any rate, the shorter fibres have a greater fibre-weight per inch. It is only among the *hirsutum* cottons, however, that this phenomenon occurs frequently; apart from these, the very coarse cottons Mollisoni and Aligarh A. 19 alone exhibit the same feature in both seasons. Generally speaking, the feature is not well marked in Indian indigenous cottons, so that in this respect they resemble the Sakel cottons on which tests were made by Balls and by Morton.

We may now inquire how the results obtained by taking into consideration the variation of fibre-weight with fibre-length compare with those obtained by the ordinary cutting method. Unfortunately, tests by the ordinary method were not made on the lint taken from the *kapas*, but such tests had already been made on the lint of these cottons supplied at the same time as the *kapas*; of course, the lint from the *kapas* cannot be regarded as a true sample of the lint supplied as such, for, as Morton has shown,[7c] even in a single bale of lint there may be wide variations of fibre-weight. However, the results obtained by the ordinary method compare very favourably on the whole with the mean values calculated from the results of the present tests, the difference on the average amounting to some 5·7%, although in the most divergent case it amounted to 19 per cent. The difference is generally no more in the case of the cottons which show great variation of fibre-weight with fibre-length than it is with those showing little variation; thus, for three out of five cottons grown in America, the results are almost exactly the same by the two methods. It is to be noted that for all tests on those cottons lint used was from the same stock bale—and not from *kapas*—so that sampling errors are likely to have been less in these cases. It is therefore concluded that the errors involved in the cutting method are not sufficient to invalidate it, so far as concerns the variation of fibre-weight for different lengths of fibre. The objection that in this method short fibres are ignored seems therefore to be a small one; moreover, it has to be remembered that in the spinning processes much of the short fibre is removed as fly or card strips, and therefore its omission in the fibre-weight test may really be an advantage as attention is thereby confined rather to those fibres that compose the spun

yarn. But it must not be forgotten that there still remains the possibility that the cutting method may give rise to erroneous results owing to the variation of fibre-weight along the length of a single fibre.*

(2) The Number of Cotton Fibres per Seed

As explained on page T421 the results of these tests make it possible to calculate the numbers of fibres of different lengths per seed; the values obtained are included in the Appendix, Tables **Ib–IVb.**

The curves of Figs. 1–3 show the distribution of fibre-length as obtained by means of the Balls sorter. Now the sorter curve shows the percentage weight of each group-length; but it does not show the percentage distribution of fibre-length according to the number of fibres. The distribution-curve according to number is however related to the sorter curve, and may be obtained from it by taking into consideration the unit fibre-weight for each group-length. We will consider the following three cases in turn—(1) the fibre-weight per inch is the same for different lengths; (2) the fibre-weight per inch is greater for short lengths than for longer lengths; (3) the fibre-weight per inch is less for short lengths than for longer lengths.

If the fibre-weight per inch is the same for different lengths of fibre, the *unit* fibre-weights will be proportional to the lengths of the fibres, so that for equal percentage weights of, say, ½-inch and 1-inch fibres, the *number* of ½-inch fibres would be twice as great as that of 1-inch fibres. Hence if curves of equal area are drawn to show the distribution of fibre-length by weight and by number of fibres, the percentages by number of the shorter lengths will be higher than the percentages by weight, whereas the percentages by number of the longer lengths will be less than the percentages by weight. An example of this is Wagad 8, 1926–27, the curves for which are shown in Fig. 4 (middle).

But if the fibre-weight per inch is greater for short lengths than for longer lengths, then the difference in fibre-weight per inch compensates to some extent for the difference in fibre-length, so that in this case the *unit* fibre-weights of shorter and longer fibres are not so different as they would be if the fibre-weight per inch were constant. As a consequence, the distribution-curves by weight and by number of fibres more nearly coincide than they do when the fibre-weight per inch is constant. And if in an extreme case the fibre-weight per inch were inversely proportional to the length, the *unit* fibre-weight would be the same for different lengths and the distribution-curves by weight and by number would be identical. P.A. 4F, 1926–27, is an example in which the fibre-weight per inch for short lengths is greater than that of longer lengths; the distributions of fibre-length for this cotton by weight and by number of fibres are given in Fig. 4 (top).

On the other hand, if the fibre-weight per inch of longer lengths is greater than that of shorter lengths, then this difference is accentuated in the unit fibre-weights, as these take account both of the lengths and of the fibre-weights per inch. Hence, in this case the distribution-curves by weight and by number of fibres diverge from one another even more than in the case where the fibre-weight per inch is the same for different lengths. Wagad 4, 1927–28, is the only cotton for which the longer lengths have appreciably

*This warning note is sounded because the results of the parallel investigation, which will be published shortly, make it clear that the cutting method may in fact give substantially different results from those obtained when whole fibres are weighed.

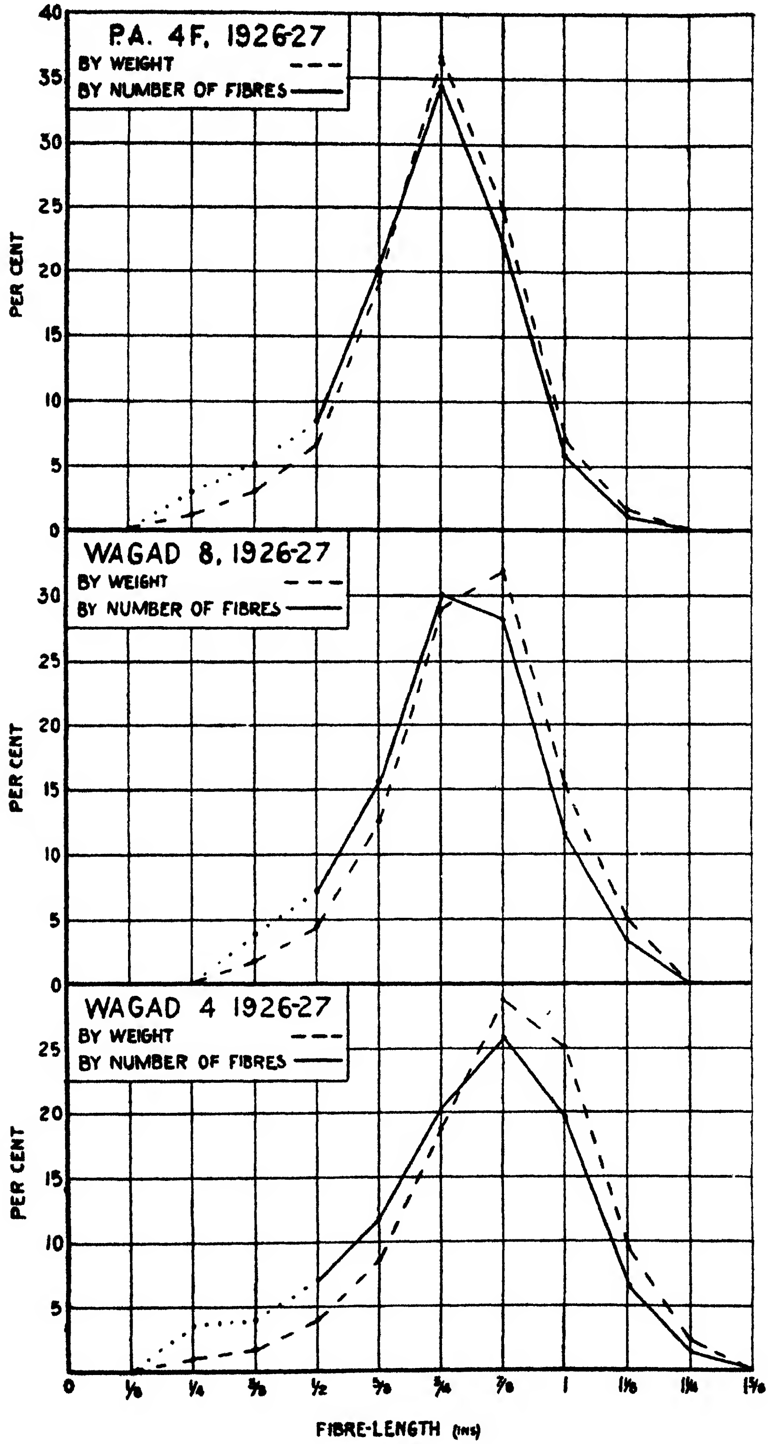

Fig. 4.

FIBRE-LENGTH DISTRIBUTIONS BY WEIGHT AND BY NUMBER OF FIBRES

higher weight per inch than the shorter lengths. The distributions of fibre-length for this cotton by weight and by number of fibres are also included in Fig. 4 (bottom).

Reviewing the results as a whole, we see that the length-distribution by number of fibres is only approximately represented by the sorter-distribution by weight. For nearly all the *herbaceum*, *neglectum*, and *indicum* cottons, the divergence is similar to that shown for Wagad 8, Fig. 4; and for A. 19, Mollisoni, and the *hirsutum* cottons, the divergence is less, and similar to that shown for P.A. 4F, Fig. 4. The chief differences occur at the extreme ends of the curves, where for the shorter fibres the frequency by number of fibres is about double the frequency by weight, and for the longest fibres the frequency by number of fibres is decidedly less as a rule than the frequency by weight; in the region of the mode the difference in frequency is comparatively small.

We may now discuss certain points connected with the average number of fibres per seed. Table III shows the average number of fibres per seed for each cotton for each season; it includes also certain average figures obtained from the results given in Technological Reports, 1929[2a]; these figures have been obtained by first multiplying the average fibre-length for all seasons available by the average fibre-weight per inch for the same number of seasons; the product represents of course the average weight of a single whole fibre; the lint-weight per seed, expressed in the same units, is then divided by this product, the result being the average number of fibres per seed. The values thus obtained are not all equally trustworthy, because the figure for the lint-weight per seed is in some cases the result for a single season only. The same table also contains the values for seed-weight and lint-weight per seed for the two seasons 1926–27 and 1927–28; these figures may be compared with the figures in column 4 and 7 showing the corresponding figures given in Technological Reports.

As a general rule, the higher values are not very different from the values given in Technological Reports; exceptions are Wagad 4, Wagad 8, Hagari 25, and Mollisoni—all of which have higher seed-weight and lint-weight than the values given in Technological Reports—and the three Punjab-Americans 4F, 285F, and 289F, which have decidedly lower values than those given in Technological Reports, the difference in the case of 285F being very large indeed.

It will be observed that the number of fibres per seed may differ greatly for different species, or for different varieties of the same species, or even for the same variety in different seasons. Thus, for the intra-specific differences, we note that among the *herbaceum* cottons, Wagad 8 has more than twice as many fibres as Dharwar 1 or Hagari 25; among the *indicums*, Karunganni has nearly twice as many fibres as Nandyal 14; and among the *hirsutums*, Cambodia Co. 1 has nearly twice as many fibres as Cawnpore-American C.A. 9. Generally speaking, the average numbers of fibres per seed as calculated from the results given in Technological Reports agree quite well with the numbers obtained in the present series of experiments, the only outstanding exceptions being the Punjab-Americans 4F, 285F, and 289F.

With reference to the seasonal effect on the number of fibres per seed and its relation to the seed-weight and lint-weight, the following observations may be made—A few cottons give much the same results for all particulars in both seasons; these are J.N. 1, Karunganni, Gadag 1, and Cambodia Co. 1.

Table III
The Average Number of Fibres per Seed

Cotton	Seed-weight (mgm.)			Lint-weight per Seed (mgm.)			Number of Fibres per Seed		
	Present Tests		Tech. Reports	Present Tests		Tech. Reports	Present Tests		Tech. Reports
	1926–27	1927–28		1926–27	1927–28		1926–27	1927–28	
Dharwar 1	56	50	54	23	20	19	4,200	4,200	3,900
Surat 1027 A.L.F.	69	68	64	37	36	36	5,800	6,800	6,200
Wagad 4	79	55	69	52	28	40	9,000	7,200	7,600
Wagad 8	80	60	71	58	38	47	10,600	10,000	8,800
Hagari 25	56	62	53	18	25	18	3,700	5,000	4,000
Cawnpore K. 22	50	48	49	35	31	33	6,700	6,700	6,600
Bundelkhand J.N. 1	41	40	40	25	24	24	5,200	5,100	4,700
Aligarh A. 19	51	44	54	36	33	34	5,800	5,500	5,600
Mollisoni	46	61	50	28	36	32	5,000	5,100	5,200
Umri Bani	50	49	52	20	19	22	4,300	5,000	5,100
Nandyal 14	43	43	46	14	13	14	2,500	2,800	3,000
Karunganni	47	49	50	23	23	25	5,000	5,200	5,700
Gadag 1	97	99	97	48	51	44	13,200	12,900	11,500
P.A. 4F	44	73	81	22	36	40	7,200	8,700	10,200
P.A. 285F	50	62	90	22	28	39	8,700	7,800	12,000
P.A. 289F	38	82	91	17	34	38	8,500	9,000	11,300
C.A. 9	80	69	75	36	33	34	8,900	7,800	8,300
Cambodia Co. 1	111	116	120	60	63	62	14,900	14,100	15,000

In other cases the seed-weight, lint-weight, and unit fibre-weight change together; thus Dharwar 1, Wagad 8, A. 19, K. 22, each have less seed-weight, lint-weight, and fibre-weight in 1927–28 than in 1926–27, but as the change in the unit fibre-weight is almost exactly proportional to the change in the lint-weight per seed, the number of fibres per seed in these cases remains practically unaltered. In the case of Wagad 4 the decrease in the unit fibre-weight for 1927–28 is not so great as the decrease in the lint-weight per seed, and consequently the number of fibres per seed is decidedly less in 1927–28. The Punjab cottons, Mollisoni, 4F, 285F, and 289F, have much greater seed-weight, lint-weight, and fibre-weight in 1927–28; Surat 1027 A.L.F., Umri Bani, and Nandyal 14, show no change in seed-weight or lint-weight in the two seasons, but have lower unit fibre-weight in 1927–28, and hence have a higher number of fibres per seed in that season. On the other hand, Hagari 25 shows no change in unit fibre-weight but has greater seed-weight and lint-weight per seed, and therefore a greater number of fibres per seed in 1927–28. Cawnpore-American C.A. 9 is peculiar in that both seed-weight and lint-weight per seed are less in 1927–28, but the unit fibre-weight is greater, so that the number of fibres per seed is decidedly less.

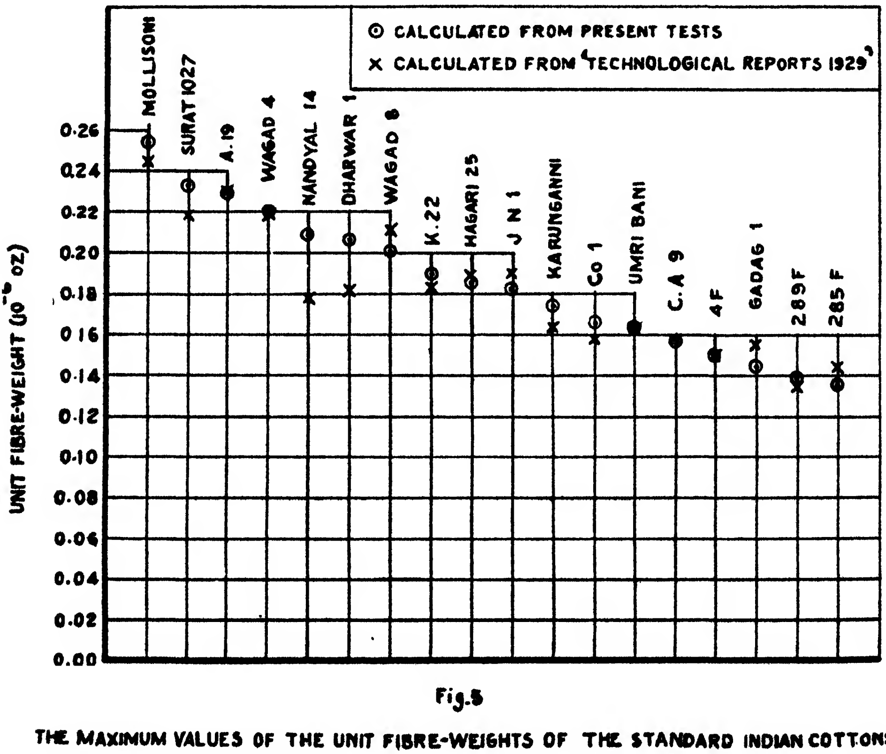

Fig. 5

THE MAXIMUM VALUES OF THE UNIT FIBRE-WEIGHTS OF THE STANDARD INDIAN COTTONS

The results in the present paper may be used to test the relationships discussed in the previous paper, viz. the relationships between the number of fibres per seed and (1) the lint index, (2) the ratio of the lint-weight per seed to the seed-weight, and (3) the ginning percentage. It was pointed out that if for all cottons the number of fibres per seed were proportional to the lint index, then the unit fibre-weight must be the same for all cottons. That this

can hardly be true is apparent from the fact that the unit fibre-weight depends upon the conditions of growth, being less under unfavourable conditions. To investigate whether the unit fibre-weight is the same for all cottons under optimum conditions of growth we may select the higher value of the two seasons as more nearly representing the unit fibre-weight for optimum conditions. These higher values are given in Table IV, and have been plotted in Fig. 5, from which it will be seen that the values of unit fibre-weight differ considerably from one another, the highest being nearly twice that of the lowest, with a fairly regular gradation between. These values may be compared with the values obtained by multiplying the results given in Technological Reports for average fibre-length and for the fibre-weight per inch. We again select the highest value obtained for each cotton in the four to six seasons available; the results have also been included in Table IV and Fig. 4, and agree very closely with those obtained in the present series of test, the only noteworthy exceptions being Dharwar 1 and Nandyal 14.

Table IV

The Unit Fibre-weights of Standard Indian Cottons

Cotton	Present Tests		Tech. Reports 1929		
	Season	Unit Fibre-weight 10^{-6} oz.	Unit Fibre-weight 10^{-6} oz.	Season	No. of Seasons*
285F	1927–28	0·135	0·144	1925–26	6
289F	1927–28	0·139	0·134	1927–28	5
Gadag 1	1927–28	0·144	0·155	1923–24	6
4F	1927–28	0·150	0·150	1928–29	5
C.A. 9	1927–28	0·156	0·158	1926–27	5
Umri Bani	1926–27	0·162	0·162	1926–27	5
Co. 1	1927–28	0·165	0·158	1928–29	6
Karunganni	1926–27	0·174	0·163	1926–27	5
J.N. 1	1926–27	0·182	0·190	1924–25	5
Hagari 25	1927–28	0·185	0·189	1923–24	6
K. 22	1926–27	0·190	0·183	1927–28	5
Wagad 8	1926–27	0·201	0·211	1926–27	4
Dharwar 1	1926–27	0·206	0·182	1926–27	5
Nandyal 14	1926–27	0·209	0·178	1923–24	6
Wagad 4	1926–27	0·221	0·219	1926–27	4
A. 19	1926–27	0·229	0·230	1928–29	5
1027 A.L.F.	1926–27	0·233	0·218	1925–26	5
Mollisoni	1927–28	0·254	0·244	1927–28	4

*The values of unit fibre-weight given in column 4 are the highest values so far recorded in the testing of the standard cottons during a number of seasons, the number of seasons being given in the last column.

Although these results are subject to error, as previously pointed out, because they do not take cognisance of the variation of fibre-weight along the length of a single fibre, yet the differences between them are of such an order as to make it quite clear that the unit fibre-weight is really different for different cottons, and that therefore the number of fibres per seed cannot be proportional to the lint-index.

If the number of fibres per seed were proportional to the ratio of the lint-weight per seed to the seed-weight, then the unit fibre-weight should be directly proportional to the seed-weight; for the 36 pairs of values available it is found that the correlation coefficient is $-0{\cdot}238$; the negative value

actually indicates a tendency for *low* fibre-weight to be associated with *high* seed-weight. However, such a small correlation from 36 pairs of values would be expected about once in six times as a result of random sampling alone,[9] so no importance can be attached to its actual value or negative sign. Nevertheless, it completely rules out the possibility that for all cottons the unit fibre-weight is directly proportional to the seed-weight. But this does not exclude the possibility of a high positive correlation existing under more restricted conditions, e.g. for different varieties of a single species, or for different values obtained for a single variety grown under different conditions; thus, for the 14 pairs of values of the *hirsutum* cottons the correlation coefficient between unit fibre-weight and seed-weight is comparatively high, viz. $+0{\cdot}574$. The chance that such a correlation may be obtained as a consequence of random sampling[9] is only about one in 30, so this correlation is possibly "significant," though of course it is far from indicating direct proportionality between the two quantities.

Finally, the correlation coefficient between the number of fibres per seed and the ginning percentage for the 36 pairs of values is $+0{\cdot}33$, a value which may be expected about once in 20 times as a consequence of random sampling.[9] This correlation is therefore doubtfully "significant"; in any case it shows that there is no approach to direct proportionality between the two quantities when different species of cottons are included, and the value is much smaller than was obtained by Leake, who confined his investigation to Asiatic types only.

We conclude therefore that not one of the three relationships is so wide in its application as to embrace all types of cotton.

IV—CONCLUSIONS

(1) It cannot be accepted as universally true that the fibre-weight per unit length is the same for different lengths of fibre of a given cotton.

(2) Among *hirsutum* cottons, the fibres of longer length of a given cotton generally have less fibre-weight per inch.

(3) The *herbaceum, neglectum,* and *indicum* cottons do not generally show any large change of fibre-weight with fibre-length; the chief exceptions are Aligarh A. 19 and Mollisoni, both of which have in each season a much less fibre-weight in the longer lengths.

(4) In spite of the variation of fibre-weight with fibre-length in some cases, the effect upon the mean fibre-weight is not sufficient to make this essentially different from the value obtained by the ordinary cutting method, in which any such variation is ignored. But there still remains the possibility that the cutting method may give rise to erroneous results owing to the variation of fibre-weight along the length of a single fibre.

(5) The number of fibres per seed may differ greatly for different species, for different varieties of the same species, or for the same variety in different seasons.

(6) For a series of cottons differing from one another not only in their conditions of growth, but also in variety and species, there is no direct proportionality between the number of fibres per seed and (1) the lint index, or (2) the ratio of the lint-weight per seed to the seed-weight, or (3) the ginning percentage.

ACKNOWLEDGMENTS

The participation of one of us (R.N.L.I.) in the work described in the present paper has been made possible by the grant of a Research Studentship by the Indian Central Cotton Committee.

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APPENDIX

Table I

Herbaceum Cottons

A—Ginning Percentage and Number of Fibres per Seed

Cotton	Season	Weight of Seed (mgm.)	Weight of Lint per Seed		Ginning Percentage	Mean Fibre-length (inch)	Mean Fibre-weight per inch 10^{-7} oz.	Mean Number of Fibres per Seed
			Mgm.	10^{-3} oz.				
Dharwar 1	1926–27	55·9	23·2	0·818	28·7	0·92	2·24	4,160
	1927–28	50·4	19·8	0·698	27·7	0·92	1·92	4,220
Surat 1027 A.L.F. ...	1926–27	69·2	36·9	1·302	34·7	1·02	2·30	5,840
	1927–28	68·1	35·9	1·266	35·0	1·00	1·99	6,840
Wagad 4	1926–27	79·0	52·0	1·834	39·6	0·86	2·57	9,030
	1927–28	54·6	28·0	0·988	34·5	0·86	1·74	7,170
Wagad 8	1926–27	80·0	58·0	2,046	41·6	0·81	2·47	10·640
	1927–28	59·8	38·4	1·354	38·5	0·80	1·80	9,990
Hagari 25	1926–27	55·6	18·4	0·649	24·8	0·88	2·08	3,710
	1927–28	61·6	25·0	0·882	28·6	0·88	2·11	4,960

B—Distributions of Fibre-length, Fibre-weight per Inch, and Number of Fibres per Seed

Cotton	Season		Group-length										
			¼"	⅜"	½"	⅝"	¾"	⅞"	1"	1⅛"	1¼"	1⅜"	1½"
Dharwar 1	1926–27	Sorter percentage ...	...	1·2	3·2	6·6	12·1	22·2	33·2	17·8	3·8	...	...
		Weight per inch ...	...	...	...	2·20	2·25	2·26	2·25	2·23	2·18	...	...
		No. of fibres per seed	...	120	230	400	590	920	1210	580	110	...	.
	1927–28	Sorter percentage ...	1·0	1·8	2·8	6·3	13·4	25·0	29·4	14·6	4·7	1·0	..
		Weight per inch ...	...	...	.	1·99	2·00	1·95	1·94	1·89	1·77	...	...
		No. of fibres per seed	140	170	200	350	630	1020	1050	480	150	30	...
Surat 1027 A.L.F. ...	1926–27	Sorter percentage ...	...	1·0	1·8	4·4	7·5	12·6	24·9	28·7	15·1	4·0	.
		Weight per inch ...	...	...	.	...	2·25	2·32	2·28	2·30	2·30	...	...
		No. of fibres per seed	...	150	210	410	580	800	1410	1440	680	160	...
	1927–28	Sorter percentage ...	0·6	1·2	1·8	3·6	7·1	13·3	29·2	28·2	12·0	3·0	
		Weight per inch ...	...	...	...	2·08	2·04	2·02	2·00	1·97	1·89	...	. .
		No. of fibres per seed	160	210	240	390	650	950	1850	1610	640	140	. .
Wagad 4	1926–27	Sorter percentage ...	1·2	1·8	3·8	9·3	18·9	30·1	26·5	6·6	1·7	...	...
		Weight per inch ...	...	...	2·60	2·46	2·51	2·58	2·63	2·65	...	...	. .
		No. of fibres per seed	350	350	560	1120	1840	2460	1850	410	90	...	...
	1927–28	Sorter percentage ...	1·0	1·7	4·0	8·6	18·8	28·8	25·1	9·6	2·4	...	...
		Weight per inch ...	...	...	1·63	1·63	1·71	1·76	1·77	1·80	...	...	...
		No. of fibres per seed	260	290	500	840	1450	1850	1400	470	110	...	...
Wagad 8	1926–27	Sorter percentage ...	...	1·8	4·4	12·5	29·0	31·9	15·2	4·9	...	...	...
		Weight per inch ...	...	...	2·44	2·48	2·48	2·48	2·53	2·41	...	...	...
		No. of fibres per seed	...	420	760	1650	3190	3010	1240	370	...	...	...
	1927–28	Sorter percentage ...	1·2	2·3	5·3	14·5	27·5	28·8	13·8	5·2	1·4	...	...
		Weight per inch ...	...	...	1·95	1·83	1·80	1·78	1·80	1·81	...	...	...
		No. of fibres per seed	340	440	760	1710	2760	2510	1040	350	80	...	...
Hagari 25	1926–27	Sorter percentage ...	0·6	1·4	2·4	7·4	20·6	31·0	25·3	8·5	2·8	...	...
		Weight per inch ...	...	...	...	2·12	2·10	2·09	2·09	1·97	..	...	...
		No. of fibres per seed	60	120	130	300	850	1130	800	240	80	...	...
	1927–28	Sorter percentage ...	0·9	1·8	2·8	6·4	15·4	31·2	27·2	11·7	2·6	...	...
		Weight per inch ...	...	...	...	2·28	2·24	2·15	2·04	1·93	...	...	...
		No. of fibres per seed	140	180	210	400	810	1470	1180	480	90	...	...

APPENDIX—*continued*

Table II

Neglectum Cottons

A—Ginning Percentage and Number of Fibres per Seed

Cotton	Season	Weight of Seed (mgm.)	Weight of Lint per Seed		Ginning Percentage	Mean Fibre-length (inch)	Mean Fibre-weight per inch 10^{-7} oz.	Mean Number of Fibres per Seed
			Mgm.	10^{-3} oz.				
Cawnpore K. 22 ...	1926–27	50·2	34·9	1·231	40·5	0·75	2·54	6,730
	1927–28	47·5	30·7	1·083	38·5	0·74	2·28	6,740
Bundelkhand J.N. 1	1926–27	41·1	24·6	0·868	37·1	0·77	2·36	5,160
	1927–28	39·7	24·0	0·846	37·6	0·77	2·24	5,080
Aligarh A. 19 ...	1926–27	50·5	35·8	1·263	41·0	0·64	3·57	5,790
	1927–28	43·7	32·6	1·150	42·0	0·70	3·04	5,500

B—Distribution of Fibre-length, Fibre-weight per Inch, and Number of Fibres per Seed

Cotton	Season		Group-length										
			$\frac{1}{4}''$	$\frac{3}{8}''$	$\frac{1}{2}''$	$\frac{5}{8}''$	$\frac{3}{4}''$	$\frac{7}{8}''$	$1''$	$1\frac{1}{8}''$	$1\frac{1}{4}''$	$1\frac{3}{8}''$	$1\frac{1}{2}''$
Cawnpore K. 22 ...	1926–27	Sorter percentage ..	1·4	2 0	4·8	19·0	37·8	26·2	8·8	...	...	. .	...
		Weight per inch ..	...	...	2·76	2·62	2·52	2·52	2·52	...	...	...	...
		No. of fibres perseed	250	240	450	1430	2460	1470	430	...	...	...	...
	1927–28	Sorter percentage ...	1·0	2·2	6·9	20·3	40·5	21·6	6·2	1·4	..	...	...
		Weight per inch ...	...	...	2·40	2·30	2·28	2·25	2·18	...	...	...	...
		No. of fibres perseed	180	260	640	1530	2570	1190	310	60	...	.	...
Bundelkhand J.N. 1	1926–27	Sorter percentage ...	1·2	2·6	6·0	13·6	35·8	30·6	8·8	1·4	...	...	...
		Weight per inch .	...	...	...	2·40	2·36	2·33	2·32	...	...	...	...
		No. of fibres perseed	170	250	440	780	1760	1360	350	50	...	...	...
	1927-28	Sorter percentage ...	0·4	1·3	4·0	14·2	42·4	31·2	5·2	1·4	...	...	...
		Weight per inch ...	...	...	2·43	2·28	2·25	2·22	2·17	...	...	...	...
		No. of fibres perseed	60	130	290	850	2120	1360	220	50	...	...	...
Aligarh A. 19 ...	1926–27	Sorter percentage ...	1·7	3·8	15·4	44 9	30·7	3·5	...	...	...	...	...
		Weight per inch ...	...	...	3·84	3·63	3·42	...	...	...	...	...	...
		No. of fibres perseed	230	350	1050	2500	1510	150	...	...	...	...	...
	1927–28	Sorter percentage ...	1·3	2·6	6·7	29·3	46·0	9·8	4·3	...	...	...	...
		Weight per inch ...	...	...	3·52	3·25	3·05	2·78	...	...	...	...	...
		No. of fibres perseed	170	230	470	1660	2330	460	180	...	...	...	...

APPENDIX—*continued*

Table III

Indicum Cottons

A—Ginning Percentage and Number of Fibres per Seed

Cotton	Season	Weight of Seed (mgm.)	Weight of Lint per Seed		Ginning Percentage	Mean Fibre-length (inch)	Mean Fibre-weight per inch 10^{-7} oz.	Mean Number of Fibres per Seed
			Mgm.	10^{-3} oz.				
Mollisoni	1926–27	46·4	28·2	0·995	37·1	0·72	2·83	5,040
	1927–28	60·7	35·9	1·266	37·9	0·75	3·40	5,110
Umri Bani	1926–27	49·9	19·6	0·691	27·5	0·82	1·98	4,350
	1927–28	48·5	18·7	0·660	27·7	0·78	1·77	5,020
Nandyal 14	1926–27	43·0	14·1	0·497	24·1	0·95	2·20	2,500
	1927–28	42·7	13·3	0·469	23·0	0·93	1·87	2,830
Karunganni ...	1926–27	47·0	23·0	0·811	33·6	0·92	1·89	5,000
	1927–28	49·0	22·7	0·801	31·8	0·87	1·85	5,230

B—Distribution of Fibre-length, Fibre-weight per Inch, and Number of Fibres per Seed

Cotton	Season		Group-length									
			¼"	⅜"	½"	⅝"	¾"	⅞"	1"	1⅛"	1¼"	1⅜"
Mollisoni	1926–27	Sorter percentage ...	...	2·4	8·0	26·7	39·3	18·6	4·9	...	...	..
		Weight per inch ...	...	...	3·08	2·91	2·82	2·72	2·54	...	..	.
		No. of fibres per seed	...	210	540	1470	1860	770	190	...	..	...
	1927–28	Sorter percentage ...	0·8	1·8	5·0	17·4	43·4	25·3	5·4	0·8	...	.
		Weight per inch ...	...	...	3·86	3·64	3·43	3·24	2·90	...	.	..
		No. of fibres per seed	110	160	340	970	2130	1130	240	30	...	...
Umri Bani	1926–27	Sorter percentage ...	...	2·2	5·0	9·7	23·2	36·1	17·2	6·8	..	...
		Weight per inch ...	..	...	2·05	2·00	2·02	2·02	1·98	1·96	..	...
		No. of fibres per seed	.	200	340	530	1060	1410	600	210	..	..
	1927–28	Sorter percentage ..	1·0	2·5	5·2	14·0	30·4	32·0	12·1	2·8	..	..
		Weight per inch ...	...	...	1·86	1·80	1·79	1·77	1·68	...	...	...
		No. of fibres per seed	150	240	380	820	1490	1360	480	100	...	...
Nandyal 14 ...	1926–27	Sorter percentage ...	...	1·0	2·4	5·1	9·6	19·6	37·5	20·2	4·5	..
		Weight per inch ...	...	...	...	2·02	2·16	2·20	2·24	2·22	2·19	...
		No. of fibres per seed	...	70	120	200	290	510	830	400	80	...
	1927–28	Sorter percentage ...	0·5	1·2	2·2	4·5	10·4	24·4	40·7	13·7	2·3	..
		Weight per inch ...	...	...	...	1·82	1·86	1·94	1·92	1·81	...	...
		No. of fibres per seed	50	80	110	190	350	680	1000	320	50	..
Karunganni ...	1926–27	Sorter percentage ...	0·6	1·0	2·3	5·5	13·8	26·9	33·7	12·9	3·2	...
		Weight per inch ...	...	...	...	1·78	1·94	1·89	1·92	1·88	...	...
		No. of fibres per seed	110	120	210	410	810	1320	1420	490	110	...
	1927–28	Sorter percentage ...	0·4	1·3	3·0	7·4	20·0	32·0	23·8	9·6	2·4	..
		Weight per inch ...	...	...	...	1·90	1·88	1·86	1·81	1·74	...	...
		No. of fibres per seed	70	150	260	500	1140	1570	1060	390	90	...

APPENDIX—*continued*

Table IV

Indian *Hirsutum* Cottons

A—Ginning Percentage and Number of Fibres per Seed

Cotton	Season	Weight of Seed (mgm.)	Weight of Lint per Seed		Ginning Percentage	Mean Fibre-length (inch)	Mean Fibre-weight per inch 10^{-7} oz.	Mean Number of Fibres per Seed
			Mgm.	10^{-3} oz.				
Gadag 1	1926–27 1927–28	97·0 98·7	48·5 50·9	1·711 1·795	33·5 33·3	0·85 0·87	1·61 1·65	13,170 12,870
P.A. 4F	1926–27 1927–28	44·3 72·9	21·6 35·6	0·741 1·256	32·2 33·0	0·74 0·78	1·48 1·92	7,190 8,670
P.A. 285F	1926–27 1927–28	50·1 61·6	22·1 27·9	0·780 0·984	30·8 31·2	0·84 0·90	1·19 1·50	8,690 7,790
P.A. 289F	1926–27 1927–28	37·7 81·7	16·6 34·2	0·586 1·206	29·6 29·6	0·92 0·97	0·85 1·43	8,540 9,000
C.A. 9	1926–27 1927–28	80·1 69·1	35·7 33·2	1·259 1·171	30·7 32·4	0·88 0·87	1·67 1·79	8,950 7,680
Cambodia Co. 1 ...	1926–27 1927–28	111·0 115·6	59·9 62·6	2·113 2·208	34·7 35·0	0·95 0·95	1·56 1·74	14,890 14,080

B—Distribution of Fibre-length, Fibre-weight per Inch, and Number of Fibres per Seed

Cotton	Season		Group-length										
			¼"	⅜"	½"	⅝"	¾"	⅞"	1"	1⅛"	1¼"	1⅜"	1½"
Gadag 1	1926–27	Sorter percentage ...	0·8	1·6	3·1	7·2	21·0	40·3	21·9	4·0	...	..	...
		Weight per inch ...	..	...	1·71	1·66	1·63	1·60	1·60	1·62	...	...	..
		No. of fibres perseed	310	430	630	1190	2940	4950	2350	370	...	..	...
	1927–28	Sorter percentage ...	0·7	2·0	3·0	5·6	15·6	40·7	26·1	5·3	1·2	...	...
		Weight per inch ..	...	...	...	1·74	1·70	1·66	1·61	1·56	..	...	...
		No. of fibres perseed	170	380	440	730	2220	5440	2960	460	70	..	...
P.A. 4F	1926–27	Sorter percentage ...	1·2	3·0	6·6	19·1	36·7	24·7	7·0	1·6	...	...	...
		Weight per inch ...	..	..	1·74	1·60	1·50	1·35	1·28	...	.	...	...
		No. of fibres perseed	210	370	600	1450	2480	1580	420	80	..	...	...
	1927–28	Sorter percentage ...	0·6	1·7	4·4	14·0	35·2	32·8	8·6	2·7	...	...	..
		Weight per inch ..	...	...	2·26	2·13	1·98	1·79	1·67	...	...	..	...
		No. of fibres perseed	140	260	510	1330	2980	2620	650	180	...	...	...
P.A. 285F	1926–27	Sorter percentage ..	2·2	3·7	6·6	10·8	15·2	23·0	25 8	10·2	2·4	...	...
		Weight per inch ..	...	...	1·20	1·20	1·20	1·21	1·16	1·18	...	...	...
		No. of fibres perseed	580	660	880	1120	1320	1690	1730	590	120	...	...
	1927–28	Sorter percentage ...	0·9	1·8	4·0	7·2	13·6	25·0	31·1	12·2	3·1	1·1	...
		Weight per inch ...	...	...	...	1·59	1·57	1·54	1·47	1·40	...	...	...
		No. of fibres perseed	230	300	490	710	1140	1840	2090	760	170	60	...
P.A. 289F	1926–27	Sorter percentage ...	1·6	3·2	5·6	9·4	12·8	15·5	20·3	18·4	9·1	3·2	1·0
		Weight per inch ...	..	...	..	0·83	0·84	0·86	0·86	0·85	0·82	...	...
		No. of fibres perseed	440	600	790	1050	1190	1210	1390	1130	520	170	50
	1927–28	Sorter percentage ...	0·2	1·6	3·2	4·6	7·8	16·2	30·7	26·8	7·6	1·2	...
		Weight per inch ...	...	...	..	1·56	1·52	1·46	1·44	1·41	1·28	...	...
		No. of fibres perseed	60	330	450	570	820	1530	2570	2020	570	80	...
C.A. 9	1926–27	Sorter percentage ...	...	1·1	2·4	7·2	19·2	35·7	27·0	6·2	1·1	...	...
		Weight per inch ..	...	...	1·85	1·78	1·70	1·68	1·60	1·56	...	...	...
		No. of fibres perseed	...	210	340	820	1890	3060	2120	440	70	...	...
	1927–28	Sorter percentage ...	...	1·3	3·5	7·0	18·4	36·5	25·7	6·0	1·6	...	...
		Weight per inch ...	...	...	...	1·95	1·88	1·78	1·73	1 67	...	...	...
		No. of fibres perseed	...	210	420	680	1530	2640	1730	380	90	...	...
Cambodia Co. 1 ...	1926–27	Sorter percentage ...	...	1·5	2·4	4·8	9·7	24·2	31·1	20·4	5·9	...	...
		Weight per inch ...	...	...	...	1·62	1·65	1·59	1·53	1·50	1·59	...	...
		No. of fibres perseed	...	510	620	1000	1650	3660	4300	2530	620	...	...
	1927–28	Sorter percentage ...	1·0	1·9	3·1	4·7	9·5	17·0	31·5	23·2	5·8	2·2	...
		Weight per inch ...	...	...	...	2·01	1·93	1·85	1·71	1·61	1·49	...	..
		No. of fibres perseed	440	550	680	820	1450	2320	4060	2830	690	240	...

APPENDIX—*continued*

Table V

American *Hirsutum* Cottons

Distribution of Fibre-length, and Fibre-weight per Inch

Cotton	Season		Group-length										
			1/4"	3/8"	1/2"	5/8"	3/4"	7/8"	1"	1 1/8"	1 1/4"	1" 3/8	1 1/2"
Mississippi	1923–24	Sorter percentage ...	0·9	1·3	2·4	4·9	9·8	17·4	28·0	21·8	9·1	3·0	1·4
		Weight per inch ...	...	...	...	2·22	2·14	2·02	1·81	1·65	1·53	...	...
Memphis	1925–26	Sorter percentage ...	0·8	1·4	2·0	3·6	6·2	11·6	26·4	30·7	13·8	2.9	0·8
		Weight per inch ...	...	...	...	...	1·93	1·94	1·88	1·81	1·69	1·59	...
Texas	1923–24	Sorter percentage ...	0·6	1·7	3·1	7·4	18·0	32·4	26·7	8·0	2·0	...	...
		Weight per inch ...	...	...	...	2·22	2·04	1·90	1·74	1·62	...	...	...
	1925–26	Sorter percentage ...	0·8	1·4	2·6	6·4	15·6	33·6	29·2	8·3	2·2	...	...
		Weight per inch ...	...	...	...	2·17	2·13	1·97	1·84	1·68	...	...	...
	1926–27	Sorter percentage ...	0·5	1·5	3·4	11·0	26·8	31·3	17·3	5·8	2·4	...	...
		Weight per inch ...	...	...	...	2·66	2·43	2·29	1·43	...	...	...	..

TECHNOLOGICAL LABORATORY BOMBAY
9th May 1930

28—THE LIABILITY OF DYED WOOL TO MILDEW WITH SPECIAL REFERENCE TO THE RESISTANCE RESULTING FROM CHROMING

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The stimulating effect of alkalinity on the development of mildew on woollen and worsted materials has long been of common knowledge in the industries concerned. In a recent paper[1] the writer put forward the view that the phenomenon was due, not to the alkaline reaction, but to the presence of an increased supply of readily available food substances resulting from the hydrolytic action of the alkali upon the wool. The removal of these food substances by washing in water considerably retarded mould growth.

It was further shown that, contrary to the generally accepted opinion, the presence of acid on the wool also enhanced mildew development.

In practice the cleansing of dyed wool does not remove all traces of chemical agents or other water soluble substances, so that when such goods are stored in too moist an atmosphere, the ubiquitous spores of the fungi germinate and an unsightly growth of mildew results.

The object of this paper is to show that the use of chrome in the dyebath imparts to the wool a considerable resistance to the development of the mould fungi chiefly responsible for mildew.

Samples of wool dyed by various methods have been exposed to conditions favourable for the growth of micro-organisms and observations made on the liability of such materials to mildew development.

I. TESTS WITH LABORATORY DYED WOOL

(a) Growth of Mould Fungi on Wool dyed with Typical Dyestuffs.

Pieces of 60's quality worsted cloth were obtained which had been dyed with a selection of dyestuffs involving several methods of procedure. Duplicate samples of some of these materials were inoculated with mould spores and suspended over distilled water in large air-tight jars which were placed in a dark cellar at 20° C. Under these conditions mildew developed rather slowly but after a period of three months some useful observations could be made. The bulk of the samples were incubated at a more favourable temperature (24° C.), the progress of the experiment being accelerated accordingly.

After incubation many of the samples were covered with a luxuriant growth of green mould, chiefly *Penicillium*, whilst others either showed no growth at all, or were practically free from mould. All were examined with a binocular microscope (magnification 30 times) and some with a higher power.

Results

Table I

Dyeing Methods	No. of Samples	Mildewed extensively	Mildewed slightly	Not mildewed or only very slightly
Hydrosulphite Vat	4	4	—	—
Tin Mordant	2	2	—	—
Sulphuric acid or acetic acid and sulphuric acid	46	44	2	—
Acetic acid or ammonium acetate	19	18	—	1
Acetic acid or sulphuric acid and afterchromed	32	3	10	19
Metachrome mordant	9	4	2	3
Chrome mordant	5	2	—	3
Reduced chrome mordant ...	3	1	1	1
Neutral bath	1	1	—	—
Indigosol method (oxidised with $NaNO_2$ and chromed) ...	6	1	1	4

In addition, samples dyed with 50% Camwood and 50% Logwood, without assistants, were extensively mildewed whereas the same dyeings chromed showed high resistance.

Thus of the 131 samples exposed 49 showed considerable resistance to mildew and of these 46 had been chromed.

(b) Growth on Wool dyed with Chrome Dyestuffs With and Without Chrome.

Two 5 g. portions of worsted cloth were dyed in parallel baths with chrome dyestuffs, but one received no chrome. The temperatures of the baths and the duration of heating and washing off were the same. The dyestuffs were applied according to the makers' recipes and duplicate samples of each portion were tested for resistance to mildew in a common saturated atmosphere.

The effect of chrome was again very apparent.

Table II

Treatment	Extent of Mould Growth	
	After 88 days	After 129 days
3% Alizarin Red S Powder (Jepson).	Abundant	Very abundant
do. + 2% Bichromate	Fair	Good
3% Eriochrome Azurole B (Gy.)	Good	Abundant
do. + 1·5% Bichromate	Poor	Fair
3% Eriochrome Verdone (Gy)	Good	Abundant
do. + 1.5% Bichromate	Poor	Fair
3% Eriochrome Orange R (Gy.)	Abundant	Very abundant
do. + 1·5% Bichromate	Fair	Good

(c) The Effect of Different Assistants and Various Amounts of Chrome.

These tests were carried out on triplicate portions of scoured flannel, inoculation and conditions of incubation being as previously described.

Table III

No. of test and duration	Sample No.	Assistant	% Pot. bichromate	Observations
(1) 79 days	1	None	0·5	Slight mould growth
	2	do.	1·0	Growth almost negligible
	3	do.	2·0	do.
	4	do.	4·0	do.
(2) 80 days	1	1% Sulphuric acid	None	Good mould growth
	2	do.	0·5	Fairly good growth
	3	do.	1·0	Growth almost negligible
	4	do.	2·0	do.
	5	do.	4·0	do.
	6	None	None	Good growth
(3) 56 days	1	3% Cream of Tartar	0·5	Growth almost negligible
	2	do.	1·0	do.
	3	do.	2·0	do.
	4	do.	4·0	do.
	5	do.	None	Good growth
(4) 56 days	1	2% Formic acid	0·5	Fairly good growth
	2	do.	1·0	Growth almost negligible
	3	do.	2·0	do.
	4	No treatment	—	Very good growth

These results show that 0·5% chrome, either as CrO_3 (Tests 1 and 2) or Cr_2O_3 (Tests 3 and 4) imparts a definite resistance to mould growth, while 1% checks it. One per cent. sulphuric acid and 3% Cream of Tartar exert no effect. The untreated control (Sample 4, Test 4) mildewed much more readily than the control (Sample 6, Test 2) which presumably had lost a certain amount of soluble substance through boiling.

(d) Effect of Scouring, Acidification, and Washing.

Two series, A and B, of duplicate portions of cloth were dyed with various dyestuffs, viz. 3% Solochrome Violet R (B.D.C.), 10% Soledon Brilliant Purple RR (S.D.C.), 3% Eriochrome Flavine A (Gy), 100% Weld, 2% Supramine Red B (By.), 4% Solochrome Red B (B.D.C.), 20% Cochineal, 4% Metachrome Brown BR (Broth.), 2% Magenta Crystals (B.D.C.), 4% Anthra Wool Brown CM, 3% Omega Chrome Brown (Sandoz), and 3% Eriochrome Violet 2BX (Gy.).

They then received the following treatment—

Series A.

Scoured for 15 minutes with 1% potash olive oil soft soap, lightly rinsed, wrung and dried at 50° C.

Series B.

Treated with 5% hydrochloric acid at 70° C., rinsed etc., as before. A third series (C) comprising duplicates of six of the dyed samples, viz. Solochrome Violet R, Metachrome Brown BR, Omega Chrome Brown, Soledon

Brilliant Purple RR, Supramine Red B and Magenta Crystals, were given successive five minute baths in six lots of tap water just below boiling point and dried at 50° C.

All the pieces were inoculated with *Penicillium brevicaule* and *Aspergillus niger* and incubated in a saturated atmosphere at 24° C. Microscopical examination after two months showed the following general results.

(1) The chromed samples in Series A and B were only slightly mildewed, whereas the remainder in these series exhibited a heavy growth of mould.

(2) In Series C, mildew on the chromes was almost negligible and on the others only very slight.

Hence as far as this experiment was concerned, the chromed cloth resisted mildew in spite of the presence of small amounts of alkali or acid, whilst the immunity resulting from the removal of water soluble substances was well marked.

(e) The Relation of the Acid Assistant to Mildew.

Six samples of flannel were dyed in separate baths as follows—

Series A.

(1) 15% Glaubers Salt and 2% ammonium acetate.

(2) 15% Glaubers Salt, 2% ammonium acetate + 1% Coomassie Navy Blue 2 RNX.

(3) 15% Glaubers Salt, 2% ammonium acetate + 3% Coomassie Navy Blue 2 RNX.

Series B.

(1) 10% Glaubers Salt and 2% sulphuric acid.

(2) 10% Glaubers Salt, 2% Sulphuric acid + 0·5% Orange GG.

(3) 10% Glaubers Salt, „ „ „ + 2% „ „

All the baths were exhausted with 2% acetic acid, the cloth rinsed and three portions of each tested for mildew as before. The results were as follows—

After two months all the portions in Series A were fairly badly mildewed and approximately to the same extent. Those in Series B were also mildewed more or less uniformly but much more severely than those in Series A.

It appeared therefore that the quantity of dyestuff used was of minor importance when compared with the nature of acid used. Intensity of mildew development may have depended upon the ionisation capacity of the acid.

(f) Experiment with Indigo.

Five g. portions of flannel were dyed at room temperature in two baths containing 4 g. hydrosulphite and 3·5 and 7 cc. respectively of Indigo LL Vat I (B.D.C.). A third portion was treated for the same time with hydrosulphite only. All the baths were made slightly alkaline with ammonia. After dyeing the samples were wrung and left overnight to oxidise. They

Table IV

No.	Dyestuff	Remarks as to dyeing	Extent of mildew development
1	Acid Black	Burl dyed, nitrate of iron and myrabolan	Very badly mildewed
2	2% Naphthalene Black 4BS Holliday) ...	... ...	Badly mildewed
3	6% do.	... ...	Very badly mildewed
4	Union Black	Direct	Badly mildewed
5	4% Alliance Chrome Black ET	After chromed	Very little mildew
6	Coomassie Navy Blue 2 RNX	Direct neutral bath	Badly mildewed
7	do.	Purple A and Indigo (Hydrosulphite vat)	do.
8	do.	Dyed with a small % of chrome	do.
9	do.	Dyed with a small % of Milling Violet 4B	Very little mildew
10	3% Anthramethane Blue 3FL (Holliday)	... ...	Very badly mildewed
11	2% Acid Blue (Holliday)	... ...	do.
12	0·4% Erio Anthracene Blue R (Gy.) 0·4% Erio Glaucine BB	1% Sulphuric Acid	do.
13	3% Alizadine Brown M 1·5% Khaki Yellow WN (BDC)	After chromed	Little mildew
14	2% Alizadine Brown M 1% Khaki Yellow WN	do.	Badly mildewed
15	3% Alizadine Brown M 1% Khaki Yellow WN	do.	Fair mildew
16	Metachrome Brown B	Plus a mordant	Badly mildewed
17	2% Acid Green (Holliday)	... ...	Very badly mildewed
18	3% Fast Chrome Green 3B (R. B. Brown & Co. Ltd.)	... ...	Badly mildewed
19	Erio Fast Purple A (Gy.)	... ...	do.
20	1% do.	... ...	Very badly mildewed
21	2% do.	... ...	do.
22	1·3% Fast Wool Red B 0·4% Fast Light Orange G 0·3% Alizarine Brilliant Blue B (Holliday)	... ...	do.
23	2% Erio Fast Red BC	3% Metachrome mordant ...	Very slight mildew
24	Acetyl Rose 3GS Fast Light Yellow 3G Alizarine Brilliant Blue 3B Orange G	Acid bath...	Very badly mildewed
25	1·5% Eriochrome Violet 2 BX 2% Erio Fast Red BC	4% Metachrome mordant (Gy.)	Very slight mildew
26	0·5% Eriochrome Violet 2 BX 2% Erio Fast Red BC 0·5% Eriochromal Brown G. PDR	do.	do.
27	2% Eriochrome Violet 2 BX 2% Erio Fast Red BC 0·5 Eriochromal Brown G. PDR	do.	do.
28	1% Khaki Yellow WN	After chromed	Fair mildew
29	1·5% do.	do.	do.

were then cut in halves, one set being well rinsed, the other receiving no additional treatment. On testing for mildew the following observations were made—

> After a period of three weeks a conspicuous and approximately equal amount of growth had developed on all the unrinsed samples, including the controls. The rinsed samples, however, mildewed more slowly, a fact which might be attributed to the removal of residual alkali and other water soluble substances. In this series, also, there was no detectable difference between the amount of mildew on the control portions and that on those containing indigo.

II. TESTS WITH COMMERCIALLY DYED WOOL

For this purpose triplicate portions of commercially dyed serge cloth were inoculated with mould spores and incubated in the manner previously described*. After one month all the samples had developed mildew but to different extents. The results obtained are shown in Table IV.

The information regarding the dyeing and subsequent treatment of these samples was, in some cases, rather limited, but the results obtained agreed fairly well with those of the previous tests in that the use of chrome imparted to the cloth a greater resistance to mildew. The comparatively short period of time necessary for visible growth was, in all probability, due to the fact that the commercial cloth was not rinsed in as many changes of water as the laboratory treated pieces, and would, therefore, yield more readily available food for the mould fungi.

In all the foregoing experiments many of the samples described as badly mildewed were examined for actual fibre damage, and evidence of bacterial action. The degree of damage was found to vary with the type of mould and the intensity of growth. On the other hand, no definite indication of bacterial action was observed.

A further test was made with 12 other dyestuffs (listed on page 4), six of which were chromes. The cloth was heavily inoculated with *Bacillus mesentericus ruber* and mould spores, but no evidence of bacterial participation was obtained. Abundant mould growth occurred on all the unchromed cloth, while the chromed samples were only slightly mildewed.

Hence under the conditions of the experiments, the phenomenon of mildew must be considered to be due to the growth of those mould fungi both originally present on the wool and those purposely added and not, on the other hand, to bacteria.

It is interesting to note from the work of Thaysen and Bunker and others[7] that a marked resistance to mildew is obtained in cotton, by dyeing that material with mineral khaki (i.e., the iron-chromium treatment). A similar effect has been observed for wool in this laboratory.

DISCUSSION

The increased resistance to mildew resulting from the chroming process must be due to an adverse influence on the growth of the mould fungi concerned, either in the form of a restriction of the moisture or food supply (i.e. nutrition), or as a direct inhibitory action on growth.

* These samples were supplied by Messrs. Bullus, Grey & Co., to whom the author's thanks are due.

(a) The Effect of Chrome on Nutrition.

The micro-organisms responsible for the mildew under consideration absorb their food as a dilute solution in the moisture present. In the case of scoured worsted cloth the minimum moisture content necessary for uninterrupted growth of the mould fungi at 23°C. has been shown to be equivalent to that taken up from an atmosphere of relative humidity between 94% and 97%[2]. Hence, if the chroming process hinders the moisture regain of cloth at this high humidity, the possibility of moisture acting as a limiting factor to growth should be considered.

Pieces of worsted cloth or flannel dyed with chrome dyestuff, with and without addition of chrome, as previously described, were placed in moisture regain bottles and a slow current of air caused to pass through for three or four days. Prior to contact with the wool the air was first drawn through a number of vessels, nine in all, containing saturated aqueous solutions of potassium nitrate, which, according to Edgar and Swan[3] gives at 23°C. a superimposed atmosphere of 94% relative humidity. The whole apparatus was placed in an incubator at 23°C. In one instance (Test No. 1) four bottles containing two chromed and two unchromed samples were placed in linear series in the order specified. The remainder were exposed in pairs to parallel currents of the air. Moisture regain estimations were made in the usual manner.

RESULTS

Table V

Test No. and Exposure	Nature of Wool and Treatment	% Regain: Chromed	% Regain: Unchromed	Amount of Bichromate
(1) 3 days	Cloth dyed commercially with Alizarin	A 23·96	—	Not known
	,, ,, Acid Fast Dyes	—	B 22·56	None
	,, ,, ,,	—	C 22·45	,,
	,, ,, Alizarin	D 22·92		Not known
(2) 4 days	Cloth dyed with 3% Alizarin Red S, 10% Glaubers Salt, 3% sulphuric acid	24·38 25·12	22·08 22·79	2% 2%
(3) 3 days	Cloth dyed with 3% Eriochrome Azurole B, 10% Glaubers Salt, 2% acetic acid, 1% sulphuric acid	19·9	20·1	1·5%
(4) 4 days	As No. 3	23·48	23·53	1·5%
(5) 4 days	Flannel dyed with 1% sulphuric acid without dyestuff	24·82	24·43	1%
(6) 4 days	Cloth dyed with 3% Omega Chrome Blue FB, 10% Glaubers Salt, 2% acetic acid, 1% sulphuric acid	25·38	23·12	1·5%

Thus, in no case under the above conditions, which, it should be stated, were not constant for the tests as a group, were the chromed samples appreciably less hygroscopic than the unchromed.

These results are, to some extent, supported by the findings of Shorter, Hirst, and Hall[6] who showed that whilst wool dyed with acid dyes suffered a loss of hygroscopic capacity (Relative humidities 59% and 84·5%, Temp. 72° F.), dyeing with chromes or potassium bichromate alone did not effect its moisture absorbing powers to any marked extent. Table VI contains a selection of the actual figures obtained by these investigations.

Table VI

Moisture regains of Dyed Cloth in Atmosphere of 84·5% Relative Humidity

(Abstracted from Shorter, Hirst, and Hall)

Treatment (abridged)	Regain	Treatment (abridged)	Regain
4% Sulphuric acid ...	19·42%	3% Pot. bichromate ...	21·10%
4% Sulphuric acid +10% Sodium sulphate (Glaubers Salt)	19·72%	3% Pot. bichromate ... 2·5% Pot. bitartrate ...	20·81%
3% Orange 2G ... ... 4% Sulphuric acid ... 10% Sodium sulphate ...	18·37%	5% Potassium bichromate 10% Sulphuric acid ...	19·60%
0·5% Scarlet 6R ... 4% Sulphuric acid ... 20% Sodium sulphate ...	19·73%	3% Pot. bichromate Mor. 2·5% Pot. bitartrate ,, 5% Alizarin Orange HO	20·18%
0·3% Scarlet 6R ... ... 4% Sulphuric acid ... 10% Sodium sulphate ...	18·62%	5% Metachrome Brown 5% Metachrome Mordant	21·04%
0·3% Scarlet 6R ... ... 4% Formic acid (75%) ... 10% Sodium sulphate ...	19·63%	1% Metachrome Brown 3% Metachrome Mordant	21·33%
5% Scarlet 6R ... ... 4% Sulphuric acid ... 20% Sodium sulphate ...	17·35%	3% Pot. bichromate Mor. 1% Sulphuric acid ,, 8% Hematine XT ...	21·80%
10% Napthhalene Black BD 4% Sulphuric acid ... 10% Sodium sulphate ...	18·76 %	3% Pot. bichromate Mor. 8% Hematine XT	21·98%
		8% Eriochrome Black P.B.(conc.) ... ... 3% Acetic acid + 10% Sodium sulphate ... 1·5% Pot. bichromate ...	21·00%
		8% Eriochrome Black A 3% Acetic acid + 10% Sodium sulphate ... 1·5% Pot. bichromate ...	21·40%
		7% Solochrome Black T 2·5% Acetic acid + 10% Sodium sulphate ... 2·5% Pot. bichromate ...	21·05%
		No treatment	21·12%

In the case in point, the unchromed samples might be regarded as having been dyed with acid dyes since sulphuric acid was used as an assistant. Subsequent addition of bichromate tends to increase their hygroscopicity.

The question of moisture supply as being a limiting factor to mildew development may therefore be omitted from further consideration.

With regard to the question of the food supply, however, it was considered possible that exposure of wool to solutions of chrome, resulting as it does in the formation of a definite and very stable wool-chrome complex[4], would render it more resistant to the solvent action of water and hence

reduce the amount of food substance becoming available to the micro-organisms. In addition, a treatment which increased the fastness of a dyestuff to acid and alkali would also be expected to give protection to the fibre against the influence of weak chemical or fermentative hydrolysis. On these grounds wool dyed without chrome, especially if it contained residual acid or alkali, might constitute a more favourable substrate for growth although the quantity of readily available food would depend to a large extent upon the thoroughness of the washing-off process.

Some interesting data supporting the hypothesis that chroming adversely affects the food supply was obtained from chemical estimations of the solubility of chromed and unchromed wool at the boil as indicated by the total nitrogen content of the aqueous extract.

A sample of worsted cloth, weighing 20 g. in the constant humidity room, was boiled gently in 500 cc. distilled water under a reflux condenser for two hours. The extract was cooled and filtered.

A known volume (400 cc.) was then acidified and concentrated to about 50 cc. and the total nitrogen determined by the micro-Kjeldahl method.

In the case of the laboratory prepared samples, special care was taken to ensure that the temperature and time conditions of both the dye-bath and the extraction liquors were the same for respective pairs of chromed and unchromed samples (Samples 1 and 2, 3 and 4, Table VII), the two treatments being carried out side by side. The assistants used were 2% acetic acid, 10% Glaubers and subsequently 1% sulphuric acid, as per maker's recipe.

Samples 5 and 6 were prepared by attaching a small length of cloth (about ½lb.) to the ends of normal pieces in a commercial dyehouse.*

Table VII

Solubility of Chromed and Unchromed Wool in Boiling Water

No.	Treatment	Mg. N per 100 g. wool at 70% R.H.	
		Individual Samples	Mean
1	6% Eriochrome Black T (Gy.) ... ... 1·5% Pot. bichromate	26·61 27·84	27·23
2	As No. 1 but not chromed	36·18 36·18	36·18
3	As No. 1 but without dyestuff	40·84 38·65 39·93	39.81
4	As No. 3 but without dyestuff and chrome ...	42·76 40·23 41·46	41·48
5	Alizarin (chromed)	30·31 28·55	29·43
6	Fast acid dyes	47·70 51·46	49·58

Apart from their interest on other grounds these results are of value in the case in question only in so far as they suggest that chroming might affect the solubility of the wool at temperatures favourable to mould growth in a relatively similar manner to that exemplified for a higher temperature by the figures in the above table.

* Thanks are due to Messrs. Wm. Kitchen & Co., for the dyeing of these pieces.

Another point to be considered was the possibility of removal, by the actual chroming process, of substances which might subsequently have constituted a source of nutriment. To put this to the test two 10 g. pieces of cloth were dyed with 3% Alizarin Red S each in 500 cc. water containing 10 per cent. Glaubers salt and 3% sulphuric acid, one piece with and the other without 1% potassium bichromate. The dyeings were carried out under a reflux condenser and the conditions as to temperature and time were identical. After dyeing, the total nitrogen contained in 450 cc. of the filtered dye liquor was ascertained in the manner previously described.

The experiments were repeated and the results were as follows—

Table VIII

Solubility of Wool in the Dyebath

No.	Treatment	Mg. N. per 100 g. wool weighed at 70% R.H.
1	3% Alizarin Red S ... ... 1% Potassium bichromate	63·25
2	do. without chrome ...	49·97
3	3% Alizarin Red S ... ... 1% Potassium bichromate	64·80
4	do. without chrome ...	49·19

In this case the soluble nitrogen must have been derived from the wool itself since the molecule of Alizarin Red S lacks this element. Hence it appears clear that chroming actually removes potential food material from the wool and it is reasonable to suppose that the highly resistant keratin constituent will thereby be rendered even more inadequate as a source of food for the mildew producing organisms.

(b) The Inhibitory Action of Chrome.

In comparing the nutritive properties of chromed and unchromed wool the possibility of the chrome exercising an inhibitory or antiseptic action must not be overlooked. Such a factor, if it did exist, could not be eliminated from experiments dealing with mildew development and would be expected to be accentuated by any chemical agent or ferment which increased the solubility of the wool substance. The ultimate effect on growth would depend upon the potency and concentration of this inhibitory factor in comparison with the amount of available nutrient.

A point of interest in this connection is that moulds have been observed by Orthmann and Higby[5] to grow on the surface of chrome tanning liquors containing 7% Cr_2O_3, 8% H_2SO_4 and small amounts of sugar.

Definite evidence of an inhibitory effect on growth was obtained by two experiments described briefly as follows.

(1) Growth of Mould Fungus on Nutrient Agar.

Nutrient agar plates containing various amounts of potassium bichromate were inoculated with conidia (spores) of *Penicillium brevicaule* in petri dishes and the extent of growth measured in terms of the diameters of the "colonies" which developed.

Table IX

Growth of *Penicillium brevicaule* at 23° C. after 9 days

Concentration of bichromate on wt. of medium ...	None	·0065%	0·013%	·025%	·05%	·075%	·1%	·2%
Diam. of "Colonies" in mm. (mean of 6 inoculations) ...	65	58	32	13	4·3	3·8	2·6	0

(2) Inhibitory Action of Potassium Bichromate on Unscoured Yarn.

Small hanks of known weight of 2/39s unscoured yarn were wetted out rapidly in solutions of potassium bichromate, wrung and weighed immediately. The amount of solution taken up was thereby estimated approximately. Triplicate portions of the yarn were then inoculated and incubated in the usual manner and weekly examinations made by means of the microscope.

Table X

Effect of Various Concentrations of Potassium Bichromate on Mildew Development on Unscoured Yarn at 23° C.

wt. of wool (approx.)	Period of incubation in weeks 1	2	3
0·06	H	CCC	CCCC
0·11	H	CCC	CCCC
0·24	O	CC	CCCC
0·32	O	H	CCC
0·72	O	H	C
1·60	O	O	H
Control	CC	CCCC	

O = no growth
H = mould hyphæ present
C = mould conidiophores present
CC = ,, ,, common
CCC = ,, ,, abundant
CCCC = sample badly mildewed

The concentrations of chrome used in the former of these tests are slightly higher when reckoned on the basis of dry weight. Even in the latter case, however, quantities of loosely held chrome, far in excess of those likely to occur on dyed wool, failed to prevent a heavy growth of mould.

Two additional points are here worthy of mention. In the first place only the smallest trace of chromium could be detected in cold aqueous extracts of chromed wool and secondly, definite evidence of growth was obtained when conidia of various mould fungi, viz. *Aspergillus niger*, *A. fumigatus*, *Cephalothecium roseum* and *Penicillium brevicaule* were introduced into the aforementioned extracts obtained by boiling.

Finally, reference might be made to the influence of chrome on ferment or enzyme activity since a negative result in this connection would furnish corroborative evidence in favour of the nutrition theory as opposed to the participation of an antiseptic action.

To obtain information on this point, 2 g. strips of dyed wool were exposed for three days to the action of 100 cc. of a 9-days-old culture in peptone water

of *Penicillium brevicaule*, an organism capable of causing the disintegration of sound wool fibres, so that any enzyme present could exert its effect. A control test was also carried out by adding casein solution to the liquid in a separate sample. Formol titrations were then made on 50 cc. of the culture fluids.

Table XI

Enzyme Activity on Chromed and Unchromed Wool at 37° C. Formol Titrations: cc $N/_{10}$ NaOH (1cc. equivalent 1.4 mg. N as NH_3).

	Enzyme active	Enzyme inactivated
Wool dyed with acid fast dyes	7.15	5·50
Wool dyed with alizarin and chromed ...	5·35	4·30
Blank	6.05	4.77
1·7% Casein solution	9·60	6·35

It is clear that an enzyme had been liberated into the solution capable of bringing about the hydrolysis of both casein and peptone. It would also appear that the presence of chromed wool in the solution does not inhibit enzymic hydrolysis of the peptone. It is doubtful, however, whether the wool substance suffered decomposition either in the chromed or unchromed condition.

CONCLUSIONS

The general conclusion to be drawn from the work herein described is that the process of chroming imparts to wool a considerable resistance to the growth of the mould fungi responsible for mildew development and that this phenomenon of resistance appears to be due to the impoverishment of the wool as a source of the nutriment required by these organisms.

Special attention to thorough washing off after dyeing or scouring is beneficial and reduces the liability to mildew.

The author's thanks are due to Mr. H. R. Hirst and Dr. C. Rimington for their helpful interest and also to Mr. J. Stott who has rendered valuable assistance with the work.

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29—PURE LINEN DAMASK AND THE LAUNDRY

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INTRODUCTION

Pure linen damask is the name given to cloths of a certain type most commonly used for tablecloths and napkins, woven from pure flax yarns in a special manner so that patterns are visible even in an all-white cloth. A damask cloth is usually woven from 5 or 8-leaf satin twill constructions, which are variations from a plain weave. The warp and weft threads cross at right angles, but instead of each warp and weft thread interlacing with each weft and warp thread, each end of warp and weft passes over four ends and under one end in a 5-leaf and over seven ends and under one end in an 8-leaf; the warp end passed under is varied according to a systematic plan for each weft end, and the result is a twill formation in the cloth. At the regions where the pattern is to show, the direction of the twill is reversed and the face of the cloth is here composed of the weft floats—that is the part of the weft which passes over a number of warp threads Owing to the construction, the light is reflected in a different manner from the cloth in the ground and in the pattern, throwing the latter into sharp relief. "Single" damask is usually woven in 5-leaf twill with small patterns often repeated, and approximately the same number of warp and weft ends per inch. "Double" damask is usually woven in 8-leaf twill with a much greater number of weft than warp ends per inch; the yarns are usually finer and the patterns large and sometimes very elaborate. Several types of looms are used, but they all include the use of complicated and expensive additional parts to a plain loom.

A new linen damask cloth has such a pleasant feel and such a distinction in appearance, that it makes a universal appeal to the customer's æsthetic sense and natural pride of ownership. Many attempts are made to produce this appearance on goods not made from flax, and it must be admitted with some degree of success. The difference between the real article and the substitute is, however, always easy to see after washing It is one of the most important properties of flax fibre that its lustre is natural and permanent after washing, on the other hand, so called linen finishes on goods made from non-flax fibres are temporary and disappear on washing.

DAMAGES WHICH OCCUR IN LAUNDRY

It is naturally a matter of great concern to the user of pure linen damask cloths if they are returned from the laundry with their appearance spoiled in the slightest degree. There are several ways in which this may occur—

(1) Selvedges torn or burst.

(2) Holes in patches or indefinite, fairly straight lines parallel to the selvedge, or along the edges of straight bands in the pattern parallel to the selvedge, or less frequently similar damages parallel to the hem.

(3) One or both ends not straight but having a wavy appearance. If the pattern includes straight lines or bands across the cloth, these would be correspondingly waved.

After a sufficient number of launderings, any cloth, however good it may be, will show damages of one kind or another, and then very often

a difficult situation arises. The user complains and blames the laundry for improper handling. Very often the laundry denies this and will say the manufacturer must have been at fault, whilst the manufacturer in turn blames the laundry. This attitude of launderer to manufacturer, and vice versa, which has been so prevalent in the past, is very unfortunate, and is one which it is to be hoped will become greatly modified in the future. The publication of the results of scientific investigations into all the processes concerned in manufacture and laundering, which are being carried out by the British Launderers' Research Association and the Linen Industry Research Association, should provide the means of enlightenment of each party on the real facts of the problem and give each a respect for the other's difficulties and good intentions to serve the public as well as possible. Each trade has its own difficult technical problems to solve which do not affect the other, but there are certain problems, such as the question of the life of materials in the laundry, which do concern both parties, and by working together improvements should be possible to the advantage of all concerned.

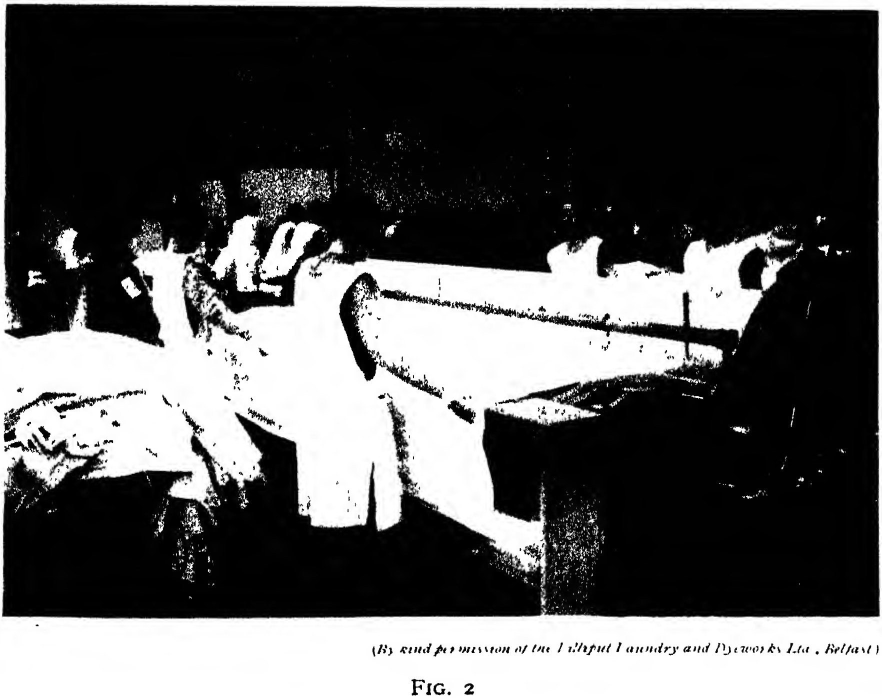
FIG. 1.

The Linen Industry Research Association has been investigating factors concerned in the life of damask at the laundry for some time, from the point of view of the construction of the cloth, thus supplementing the investigations of the British Launderers' Research Association. Damages during laundering of types 1 and 2 above may be due to the effects of the laundry processes or to the structure of the cloth, or to both together; extensive investigations are in progress to determine to what extent the structure of the cloth affects the wear, and hence to specify the requirements for maximum wearing quality. This, however, does not settle the problem, as the cost of such a cloth might be prohibitive or it might be inferior in appearance or feel to a cloth with a lower resistance to wear. Some compromise has to be made, as it is very seldom that a cloth can be

made to be the best from every standpoint. This is one of the real difficulties, that quality has to be sacrificed in order to obtain the appearance at a low cost, as cost and appearance are the chief factors apparent to the public, who do not understand cloth construction. At the same time, the consumer expects as long wear from a cheap article as from a dear one, which is unreasonable, and so the laundry and the manufacturer are frequently blamed, when really the fundamental blame is with the consumer. The manufacturer has to supply an article to the public taste, even if it is not likely to wear. This particularly applies to the nature of the patterns on damask cloths, which if unsuitable may give rise to faults of type 3 after laundering.

EFFECT OF METHOD OF LAUNDRY FINISHING

Experiments carried out by the Linen Industry Research Association in this connection have given results indicating that by a simple modification of the laundry finishing process, an increase in the life of some small damask cloths should result. An illustration of the faults of type 3 is shown in the photograph, Fig. 1, which shows the corner of a very good quality tablecloth, 3 yards by 2 yards, closely woven in 8-leaf satin twill from good yarn of two colours, showing a coloured pattern on a faintly coloured ground. The Greek key pattern which forms a border all round the cloth was very popular, but the laundry found it difficult to launder. As shown in the photograph the cloth was returned from the laundry with one end very wavy and all the straight lines in the pattern across the cloth very much distorted, moreover, wear was beginning to show as at X, due to broken warp threads at the edge of the long straight lines parallel to the selvedge. Obviously the reason for the distortion is that when the cloth was put through the Découdun machine, illustrated in Fig. 2, which drags it between a



(By kind permission of the Lilliput Laundry and Dyeworks Ltd., Belfast)

FIG. 2

moving cylinder and a stationary curved bowl to dry and glaze the cloth, parts, such as BC, have stretched more than parts such as AB in Fig. 1. Such behaviour is very often attributed by the laundry to tight threads in weaving, but obviously in this case it is connected with the pattern. As explained, a change in the weave or order of intersection of the threads is made in order to produce the pattern, and in some types this affects the amount the wet cloth can stretch when put under tension. The reason for this appears to be that in these types one or two warp threads at one side of straight bands parallel to the selvedge are not so firmly bound as the remainder, and on washing they may bend or curve inwards slightly between every eighth binding weft thread This produces a greater resistance to extension in this region than on either side. The case of straight bands across the cloth is different, as the binding is the same on both sides. The

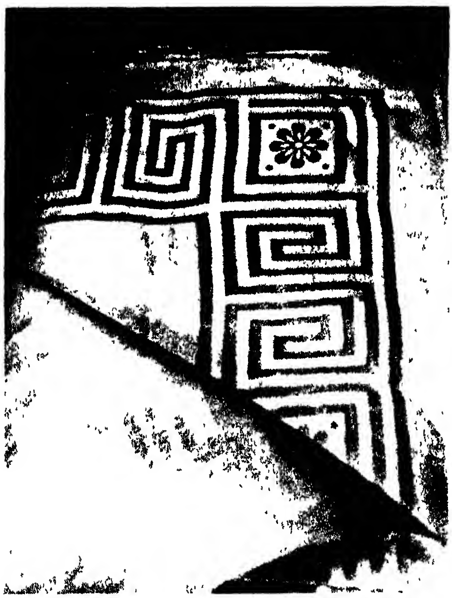


FIG 3

unequal extension on two sides of a thread in a cloth, such as the upward curves at A and B, causes the weft threads to exert what amounts to a local tearing force on one thread, which is repeated each time the cloth is washed and finished; the warp thread breaks and so lines of wear are developed more rapidly here than elsewhere. This cloth was put into the Découdun machine with the hem first, which is, we believe, the universal laundry practice. It appeared, however, from the above reasoning, that it might be preferable to finish the cloth from selvedge to selvedge, and so apply the tensions at right angles instead of parallel to the bands of cloth of unequal extensibility, since this only develops with the warp and not the weft threads In order to test the correctness of this conclusion the same cloth was thoroughly damped out and finished in the Découdun machine selvedge first instead of hem first. The result was as shown in Fig. 3. Some waviness is still apparent which may be due to the deformation in previous washes,

but the general appearance shows very considerable improvement. These cloths are generally put through the machine twice, it was found that on leaving the machine the first time the cloth was fairly dry and the starch hardened enough to prevent any possibility of being able to effect any improvement by reversing the direction at each operation.

Further experiments were carried out on other damask cloths to confirm this result and also to determine whether the direction of finishing makes any appreciable difference to the number of launderings before wear is shown. In one test two tablecloths, 63 inches by 63 inches, were taken from the same web of cloth. These were hemmed and repeatedly washed at a public laundry together with ordinary soiled goods, but whereas one cloth was always finished in the ordinary way—hem to hem—the second cloth was always finished selvedge to selvedge. The cloth was of a lower quality

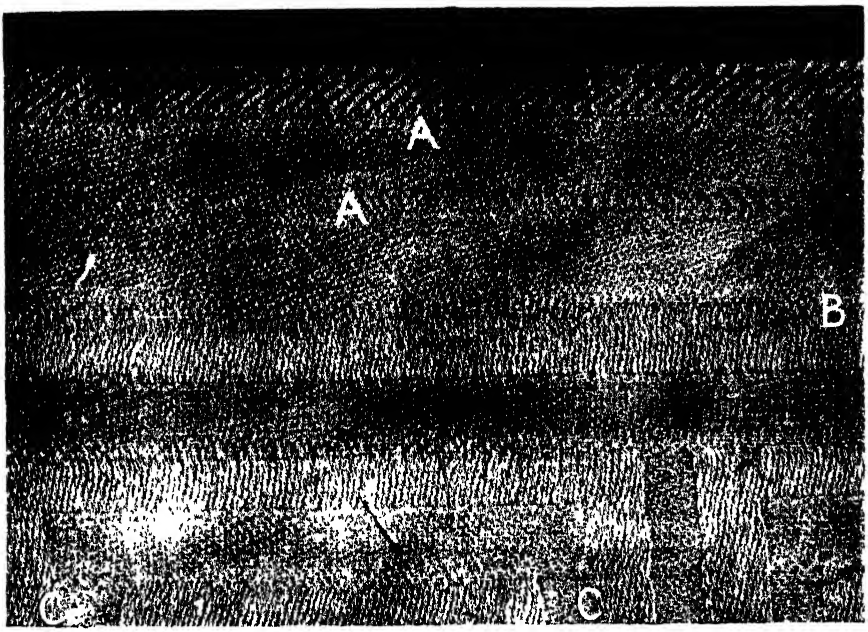


Fig. 4

than the previous one, but was made with the same Greek key pattern in 8-leaf twill on a 5-leaf ground. In this lower quality cloth the trouble with waviness of the ends was not so very pronounced, although still apparent. Fig. 4 shows an enlarged photograph of a portion of the cloth after 20 complete launderings, finished in the usual way It will be seen that at the two places marked A, close to and parallel to the selvedge the regular appearance of the cloth shows distortion into thick and thin places, which experience has shown to denote the later development of lines of holes. At the place marked B at the edge of a long straight band two warp threads are worn away over a short length, which occurred also at other places, and later on holes will develop here. At the places marked C it will be noticed that the weft threads are curved and pulled out of the straight, and corresponding

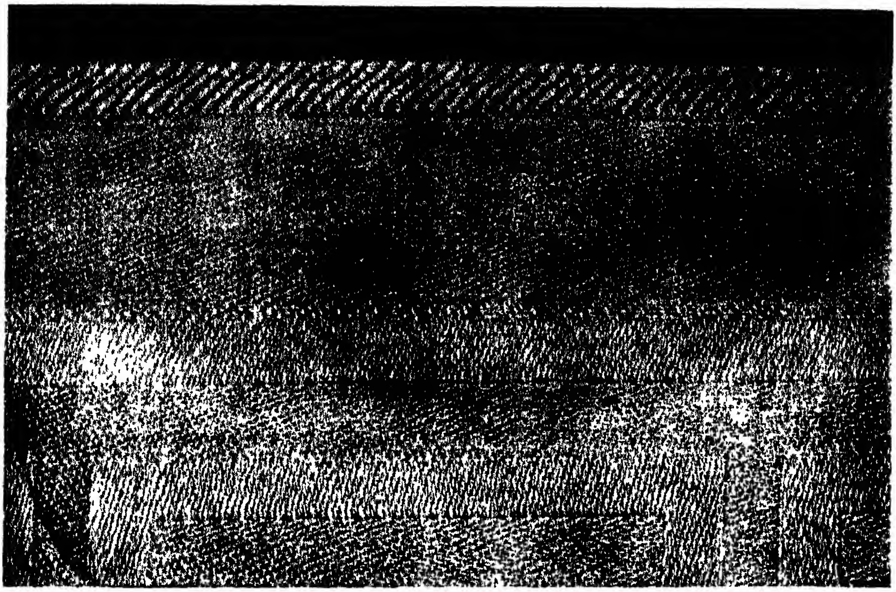


FIG. 5

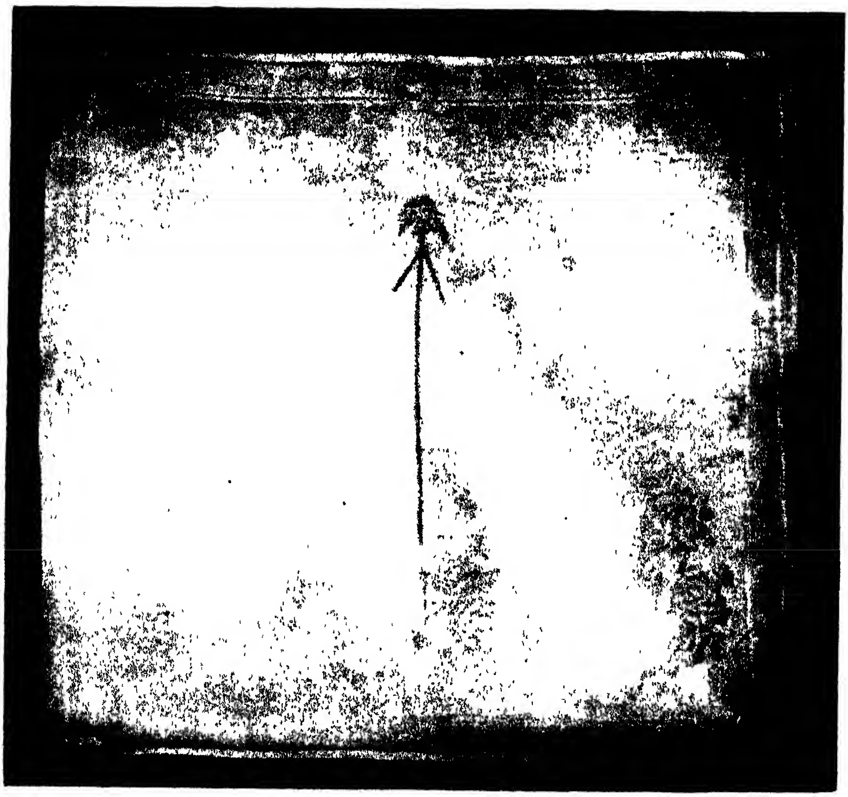


FIG. 6

waves will appear at one end of the cloth. This cloth, therefore, is definitely showing signs of wear at the edge of the bands, and some deformation of the straight lines in the pattern; this is less marked than in the previous case because of the firmer structure of the 5-leaf satin twill construction in the ground of the cloth. Fig. 5 shows a similar enlarged photograph of a corresponding piece of the second cloth, washed twenty times but finished each time from selvedge to selvedge. It shows no broken threads, the ground of the cloth between selvedge and pattern is much more uniform in appearance, and the lines of the pattern are perfectly straight, and therefore the life of this cloth will be longer than that of the previous cloth.

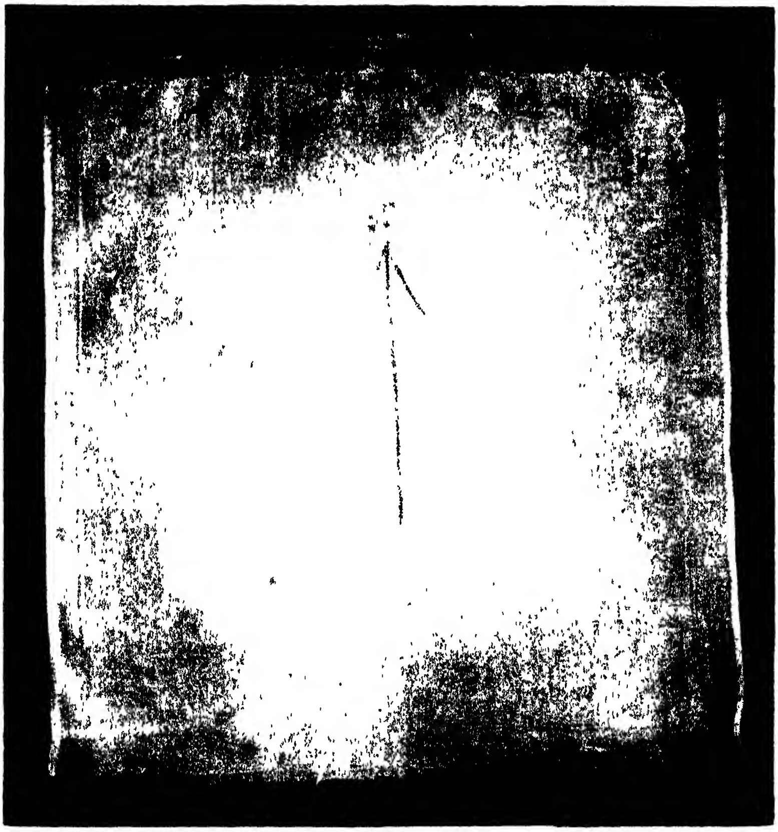
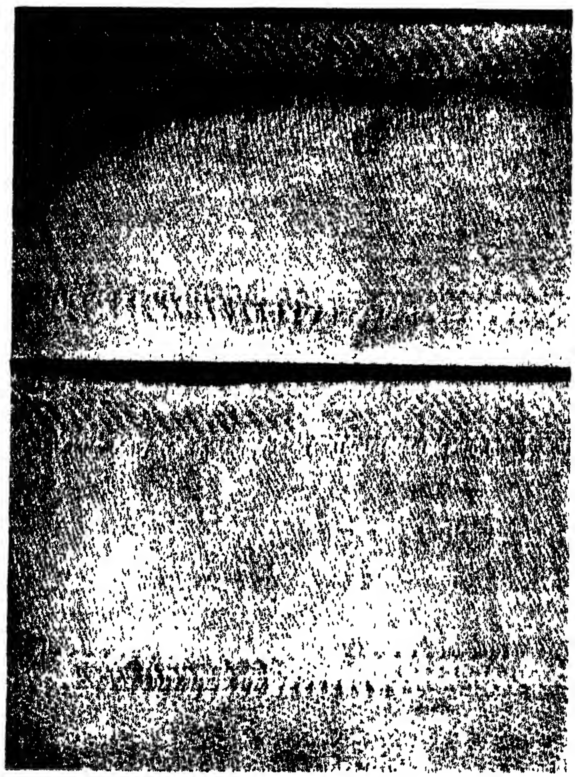


FIG. 7

Similar experiments have been made with damask napkins made in 8-leaf satin twill of fairly good quality, with a combined floral and straight-band pattern. Napkins taken from adjacent lengths of eight webs were repeatedly laundered with soiled goods in a public laundry, two from each web finished in the usual way, and two from selvedge to selvedge. Fig. 6 shows a photograph of such a napkin after twenty washes in the usual way; a very pronounced wave is apparent at one corner, with smaller ones at the other corners, all corresponding with the position of the satin bands in the pattern. Fig. 7 shows a napkin washed twenty times and finished

selvedge to selvedge, and it will be seen that the napkin is of a much better shape with straight sides and hems only slightly indented. It again appeared that the latter method of finishing, by the differential extension, reduces the wear on the threads forming the edges of long straight lines in the pattern. This is shown by comparison of the bands in Figs. 8A—10A, finished selvedge to selvedge, with those in Figs. 8B—10B, finished in the usual way. Examination of these actual cloths also shows that as a whole the wear in lines parallel and close to the selvedge in the body of the cloth is less pronounced in the cases which are finished selvedge to selvedge; this is clear from the original cloths even if it is not clearly shown by the photographs which only represent a small region of each.



CONCLUSION

It is concluded from these experiments that 8-leaf linen damask containing straight lines in the pattern should, when possible, be finished in the laundry from selvedge to selvedge. The appearance of the cloth is thus preserved and any tendency to wear along lines localised according to the pattern will be reduced. The same effects may be present in other types of damask to a less extent; they could also be finished selvedge to selvedge, which would save the laundry any need for inspection of the weave or pattern

of the cloths being treated. This alteration in the method of finishing entails no hardship on the laundry and is merely a matter of suiting the treatment to the material being used. It can be applied to all napkins and small tablecloths up to a length of 3 yards, which is the usual limiting length of the rollers in the Découdun machine. For cloths made up in longer lengths, the laundry has no alternative to the lengthwise finish. As the wear due to the differential extension may become more pronounced the longer the cloth, it should be recognised by manufacturers that patterns containing long straight lines are unsuitable for the laundry treatment and every effort be made to discourage their use for these goods.

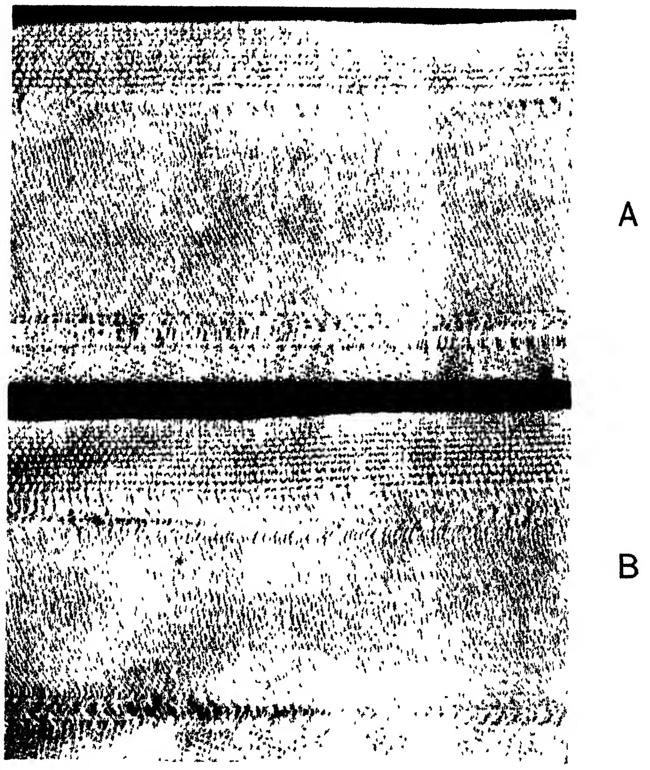


Fig. 9

It is not claimed that the faults illustrated could not be overcome by employing some other method of weaving, but as the method of weaving is chosen for several very strong technical reasons, it must be accepted as the only practical means at present available of making these goods at a reasonable price. It is considered that by the simple alteration suggested, the laundry may be able to increase the life of a large proportion of small damask cloths to an appreciable extent. The experiments were carried out in conjunction with a large modern power laundry, the Lilliput Laundry and Dyeworks Ltd., Dunmurry, Belfast, who have since adopted the process to their entire satisfaction for napkins and small good-quality cloths. In

larger poor-quality cloths some difficulty may arise from the cloth pulling out more along the hems than at the centre, but this appears possible of correction by the workers on gaining experience with this method of finishing.

The method appears to be well worth a continued trial and endeavour to determine the best means of handling all the various types of goods which have to be dealt with in a laundry. The principle stated is believed to be

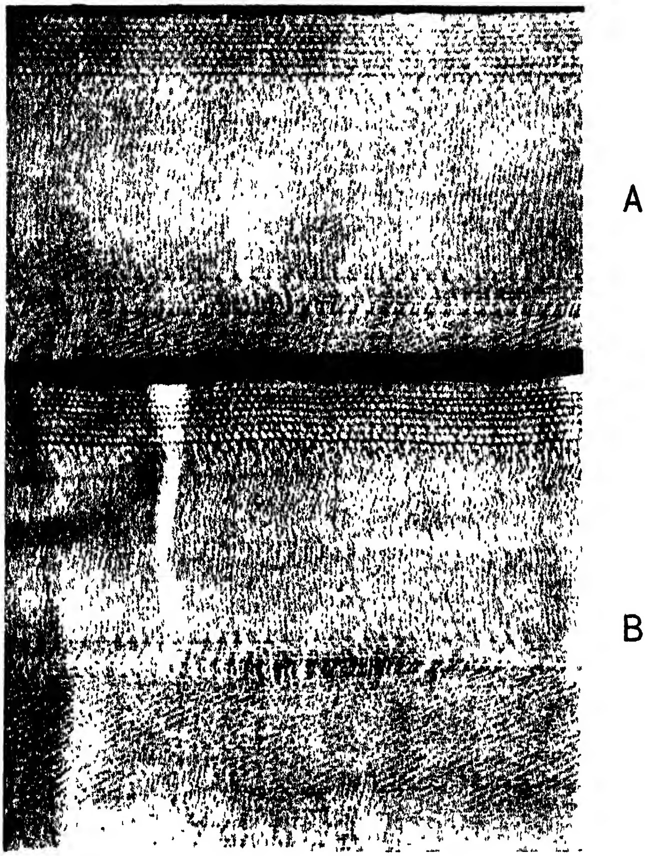


Fig. 10

sound, but the laundry's own experience is required for it to be carried out to the fullest advantage in practice.

In conclusion, I wish to express my thanks to Mr. W. McKinney, jun., of the Lilliput Laundry and Dyeworks Ltd., for his great assistance in carrying out these experiments.

THE JOURNAL OF THE
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30—THE ELASTIC PROPERTIES OF YARNS, WITH SPECIAL REFERENCE TO TIRE CORDS

By H. P. Gurney and E. H. Davis

INTRODUCTION

The purpose of this paper is to consider the nature of the elasticity of tire cord, whence it arises, why it is of technical interest to tire designers, and possible methods of measuring its value. Also, finally, in order to help to simplify future tire cord testing development, the degree to which different possible measures of elasticity are intercorrelated is considered.

Incidentally, and simply to better orientate cotton with respect to worsted, linen, rayon, and silk, and also to exhibit the major effects of plying upon cotton properties, certain other data are inserted, but these data are intended rather for qualitative, than quantitative illustration.

In "Some Tensile Properties of Cotton Yarn,"[1] Tyler Fuwa states—"There is, apparently, no definitely clear relation between the tensile strength of fabric and its durability or resistance to wear. This fact has caused engineers to place much more confidence in various tests of durability, or resistance to wear, than in ordinary measurements of tensile strength. On the other hand tensile strength will always be an important consideration in the selection of mechanical fabric."

In recent years the criterion of stretch has actively competed with, or perhaps amplified ordinary tensile tests, in the evaluation of tire cord by means of specification testing. Now it is obvious that tire cord only fails in service when it actually ruptures (or stretches to a point where it instigates separation from the adjoining rubber tread), and this rupture occurs only after a plurality of repeated stresses. To be noted, then, is that the usual tensile test is simply a one cycle extension to rupture, while service rupture involves a plurality of cycles.

The following line of reasoning may help to explain why tensile tests, though thoroughly fundamental, nevertheless need qualification in evaluating the relative merits of tire cords. In tires we are primarily interested in mileage. In repeated stress testing, mileage is proportional to cycles-to-rupture. The following empirical relation holds approximately for a wide variety of materials and probably for tire cord, at least sufficiently well to bring out the incidence of stretch.

$$\text{Cycles-to-rupture} = \left(\frac{\text{Ordinary Tensile ``One-Cycle'' Strength}}{\text{Average Testing Stress}}\right) \text{ to } n\text{-th}$$

power.

Other things being equal, in each specific case, the cycles-to-rupture will be greater, the greater the one-cycle tensile strength, the lower the testing stress, and the greater the numerical value of n. Usually, other things are

not equal, but are more or less interdependent; n particularly is more or less modified by the mean degree of fluctuation in average testing stress and the extensibility of the tire cord. As will be later shown, tensile strength and extensibility are negatively correlated.

Tire cord service is intermediate between extension to constant load and extension to constant elongation. The advent of low pressure tires has shifted the service more and more toward the latter type, and to the extent that tire cord service involves extension to constant elongation, obviously the more extensible the cord the lower the average service stress, and in accord with the foregoing relation the greater the cycles-to-rupture, the greater the mileage will be. Increase in extensibility is apt to be accompanied by diminution of tensile strength, hence extensibility cannot be carried too far without reducing cycles-to-rupture. For each tire design, manufacturing, processing, road servicing, and inflation pressure, there is an optimum combination of tensile strength and extensibility which will render maximum service. Doubtless these factors also modify n in various ways.

Except for certain pioneering work such as that of King and Truesdale,[2] and Stavely and Shepard,[3] the laws governing failure on repeated stressing or stretching of tire cord have been relatively little studied. But even though this had been the case, there would still remain the desirability of some quickly applicable routine test to gauge the uniformity of the elastic and tensile properties of different shipments, for repeated stress tests would necessarily take too much time.

Elasticity is a comprehensive term covering the general relations of stresses to strains in materials. In the restricted sense, a body is only truly elastic when stress and strain are rigorously proportional with entire absence of hysteresis. This is nearly so with steel, but not so with cotton or rubber. The elongation is the ratio of extension, in excess of initial or unstressed length, to initial length taken as unity. Set is the acquired elongation due to application of stresses or strains, and is a hysteresis or after-effect. Tensile strength is usually defined in terms of the stressing load at rupture per unit of unstressed cross-section, though it also may be based on cross-section at rupture.

THE ELASTICITY OF FIBRES

The elasticity of various textile fibres was investigated by T. Barratt[4] in "Measurements on Breaking Stresses, Extensibilities, and Elasticities of Single Fibres of Cotton, etc." Barratt measured not only the breaking loads and elongations at rupture, but also the equally important property of capacity to recover from strains. He states, "when a fibre is stretched, but without breaking, and the stretching force is then removed, the fibre does not, in general, recover its original length," and "this property of recovery from strain is one that may throw much light on the behaviour of different fibres when woven into a fabric. It is in reality, of course, a measure of true 'tensile elasticity' as distinguished from mere extensibility." It was found that the per cents elongation at rupture of linen, scoured Egyptian cotton sliver, the same mercerised without tension, natural silk, and wool, were in the order 5·1%, 7·4%, 12·2%, 18·7%, and 39·0% respectively, whereas their respective capacities of recovery from strain in arbitrary units were 0·11, 0·28, 0·34, 0·87, and 1·33; hence the same order exists with both elongation at rupture, and efficiency of recovery from strain, and the coefficient of correlation of these two series is very high: +0·98.

THE THEORY OF TIRE CORD TWISTING: ACTUAL versus MANUFACTURING TWISTS

The stretch of tire cord, particularly on the first stretch, depends not only upon the elastic properties of the cotton fibre, but also upon the twists imparted in manufacture. Three successive types of twist with two intermediate plyings are employed in making tire cord. The singles yarn twist and the second ply twist are usually right handed, while the first ply twist is usually left handed. These superposed conditions serve to modify the elastic properties of the basic fibres in such a way as to make the product more serviceable to the end in view. To clarify the relations between twist and elastic properties of tire cord, it will be necessary to define the relations between twists applied in manufacture and twists as they actually exist in the finished cord.

Fig. 1 exhibits an average extension-twist relation in determining either actual or manufacturing twists in tire cord in the conventional twist counter.

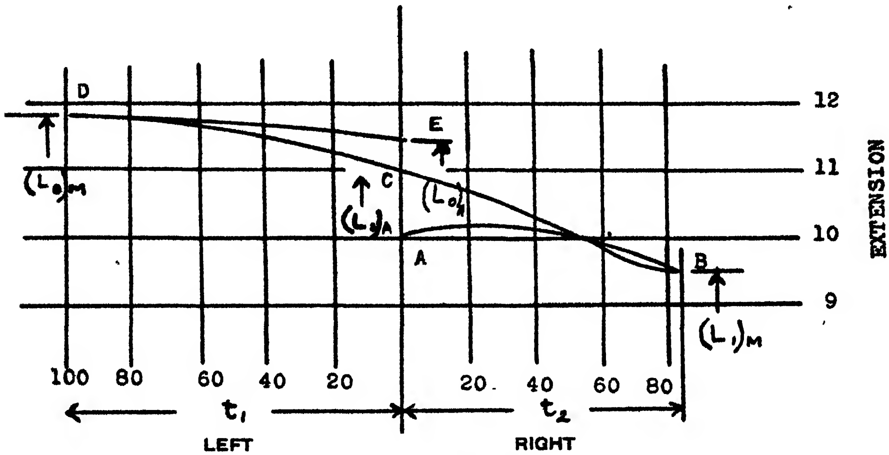

FIG. 1

Usually a 10-in. length of tire cord is employed. From A to B, t_2 turns are withdrawn from second ply twist involving a contraction from 10 to $(L_1)_M$ inches. This is the length of manufacturing first ply per unit length of finished cord. At B two of the three plies are removed. After t_2 twists are reinserted, the length at C becomes $(L_1)_A$ the actual length of first ply per unit length of finished cord. If t_1 twists are then applied from C to D as per Fig. 1, the length becomes $(L_0)_M$ the length of single yarn per unit length of finished product. At D usually all but one of the single yarns are cut or withdrawn, and manufacturing twists in single yarn are determined on a 1 in. or 2 in. length remaining. However, if twists are reinserted, contracting the single yarn to E (after removing all but one yarn at D), then the actual twists per inch in the single yarn as it finally exists in the tire cord may be directly determined on a 1 in. or 2 in. length of the yarn. In the following notation, let M refer to manufacturing twists, A to actual twists, t to observed or directly obtained twists, T to twists after reduction to a unit of length basis, sub 0 to single yarn constants, sub 1 to first ply yarn constants, and sub 2 to second ply yarn constants.

Since the actual and manufacturing second ply twists are identical, no correction whatsoever is required to convert one to another.

$$(t_2)_M = (t_2)_A \quad \text{...(1)}$$

And since in both cases, the initial length is L equal 1 or 10, as the case may be, then—

$$(T_2)_M = \frac{(t_2)_M}{1 \text{ or } 10} = \frac{(t_2)_A}{1 \text{ or } 10} = (T_2)_A \quad \text{.........................(2)}$$

Now the manufacturing first ply twist starts with an assumed zero twist at B, while the actual first ply twist starts with an assumed zero twist at C. Hence—

$$(t_1)_M = (t_1)_A + (t_2)_A \quad \text{..............................(3)}$$

But since the base lengths at B and C are neither equal nor unity (or ten), but $(L_1)_M$ and $(L_1)_A$ respectively, then to convert observed twists to unit lengths, the following relations must be applied—

$$(T_1)_M = \frac{(t_1)_M}{(L_1)_M} = \frac{(t_1)_A + (t_2)_A}{(L_1)_M} = T_{(1)A}\frac{(L_1)_A}{(L_1)_M} + \frac{(T_2)_A}{(L_1)_M} \quad \text{..................(4)}$$

$$\text{and } (T_1)_A = \frac{(t_1)_A}{(L_1)_A} = \frac{(t_1)_M - (t_2)_M}{(L_1)_A} = \frac{(T_1)_M (L_1)_M}{(L_1)_A} - \frac{(T_2)_M}{(L_1)_A} \quad \text{..................(5)}$$

Neither $(t_0)_A$ nor $(t_0)_M$ require correction, because a 1-in. length is taken (if a 2-in. length these must be divided by 2), hence—

$$(T_0)_A = (t)_{0A} \left(\text{or } \frac{(t_0)_A}{2}\right) \quad \text{..........................(6)}$$

$$(T_0)_M = (t_0)_M \left(\text{or } \frac{(t_0)_M}{2}\right) \quad \text{..........................(7)}$$

From this it follows that—

$$(T_0)_M = (t_0)_A (L_0)_A - (t_1)_A = (T_0)_A (L_0)_A - (T_1)_A (L_1)_A \quad \text{.....................(8)}$$

$$(T_0)_A = \frac{(t_0)_M (L_0)_M + (t_1)_M - (t_2)_M}{(L_0)_A} = \frac{(T_0)_M (L_0)_M}{(L_0)_A} + \frac{(T_1)_M (L_1)_M}{(L_0)_A} - \frac{(T_2)_M}{(L_0)_A} \quad \text{...(9)}$$

So that knowing $(L_0)_A$, $(L_0)_M$, $(L_1)_A$, and $(L_1)_M$, actual and manufacturing twists can be interconverted one to another.

Twists per unit length can be better visualised in terms of mean angles of inclination or lie of fibres, or yarns with respect to the axes about which they are helically twisted. Commonly this is expressed by twist factors rather than by angles of inclination. Angle of inclination can be more readily visualised, though twist factor is more readily computed.

Let α_0, α_1, and α_2 be the mean angles of inclination of single fibres to yarn axes (which will vary from zero at the axis to about $1{\cdot}5\ \alpha_0$ at the outer yarn surface), yarn axes to plied yarn axes, and plied yarn axes to cord axis, respectively.

To derive these angles of inclination from twists per unit length, certain assumptions may be tentatively made which later will acquire modification from future research work.

It will be assumed that in a two-ply yarn the mean diameter is one half the measured diameter, and that as the number of yarns plied gets larger,

this ratio will approach two-thirds. Then if D is the gauged diameter in inches—

$$\alpha_0 = \tan^{-1} \frac{K\pi(T_0)_A D}{\sqrt{\text{single yarns per cord}^*}} \quad \text{......(10)}$$

$$\alpha_1 = \tan^{-1} \frac{K\pi(T_1)_A D}{\sqrt{\text{plied yarns per cord}\dagger}} \quad \text{......(11)}$$

$$\alpha_2 = \tan^{-1} K\pi(T_2)_A D \quad \text{......(12)}$$

But in addition α_1 and α_2 may be calculated from the changes in extension of $(L_1)_A$ to $(L_0)_A$ and $(L_1)_A$ to 1 by the following relations—

$$\alpha_1 = \cos^{-1} \frac{(L_1)_A}{(L_0)_A} \quad \text{......(13)}$$

$$\alpha_2 = \cos^{-1} \frac{1}{(L_1)_A} \quad \text{......(14)}$$

Instead of angles of inclination, twist factors can be employed which is, of course, more in line with cotton technology.

$$\ddagger(p_0)_A = \frac{(T_0)_A}{\sqrt{15N(L_0)_A}}, \qquad \ddagger(p_0)_M = \frac{(T_0)_M}{\sqrt{15N(L_0)_M}} \quad \text{......(15)}$$

$$(p_1)_A = \frac{(T_1)_A}{\sqrt{3N(L_1)_A}}, \qquad (p_1)_M = \frac{(T_1)_M}{\sqrt{3N(L_1)_M}} \quad \text{......(16)}$$

$$(p_2)_A = \frac{(T_2)_A}{\sqrt{N}} \quad = \quad (p_2)_M = \frac{(T_2)_M}{\sqrt{N}} \quad \text{......(17)}$$

Finally should be mentioned the ratio of space actually occupied by the fibres of cotton to that apparently occupied by the cord assuming perfect cylindrical contour of diameter equal to the standard gauged cord thickness. If the density of cotton be assumed at 1·51 grams per cubic centimeter, then this ratio, the cotton concentration in terms of the diameter D in inches and the equivalent cord number N in hanks per pound is—

$$c = \frac{0{\cdot}000775}{ND^2} \quad \text{......(18)}$$

THE CORRELATION OF TWISTS TO PRINCIPAL PHYSICAL PROPERTIES: TENSILE STRENGTH AND ELONGATION

To bring out the incidence of these factors upon the elastic properties of tire cord, the following data, based upon tests on nine tire cords all made from the same yarn, 23s with twist factor 4·6 (22 twists per inch), and made from $1\frac{1}{16}$ in. carded American cotton of middling grade will be presented. While tensile strength and elongation may not be the ideal elastic constants, they are at least the most commonly used, and any successful method of analysing twists in tire cord must be of utilitarian value in facilitating their prediction.

In Table I is given in order—

(A) The cord diameter, D, in inches, and the equivalent size or count N in terms of hanks per pound.

* = 15 in 23/5/3s, 12 in 23/4/3s, and 9 in 13/3/3s.

† = 3 in all above constructions.

‡ The 15 applies to 23/5/3s only; for other constructions, it is the product of the last two figures.

Table I

Properties and Correlation of Nine Tire Cords Twisted up from Same Yarn

No.	D	N	$(T_0)_M$	$(T_1)_M$	$(T_2)_M$	$(L_0)_M$	$(L_0)_A$	$(L_1)_M$	$(L_1)_A$
1	0·0354	1·26	23·3	21·4	9·4	1·233	1·186	0·929	1·146
2	0·0358	1·30	21·3	17·4	6·2	1·172	1·120	0·925	1·078
3	0·0361	1·18	25·2	23·6	12·5	1·314	1·196	0·974	1·247
4	0·0353	1·31	20·6	17·7	9·6	1·220	1·181	0·957	1·144
5	0·0352	1·22	24·2	23·4	9·4	1·269	1·203	0·918	1·150
6	0·0370	1·28	20·7	20·9	6·4	1·230	1·137	0·920	1·085
7	0·0348	1·19	20·1	21·2	12·7	1·304	1·273	0·983	1·241
8	0·0338	1·23	20·0	17·0	12·4	1·235	1·218	1·002	1·204
9	0·0366	1·23	22·5	23·2	6·3	1·235	1·165	0·911	1·090
		Average	22·0 ± 1·8						

No.	$(T_1)_A$	$(T_0)_A$	(T_0) calculated	c	a_0	a_1 (a)	a_1 (b)	a_2 (a)	a_2 (b)
1	9·2	32·7	31·8	0·491	32° 10′	19° 30′	15° 00′	29° 50′	29° 20′
2	9·2	31·3	29·9	0·465	31° 10′	19° 40′	15° 40′	21° 00′	22° 00′
3	8·4	29·3	32·7	0·505	29° 50′	18° 10′	16° 30′	38° 00′	36° 40′
4	6·2	32·7	29·0	0·475	32° 00′	13° 20′	14° 20′	30° 20′	29° 00′
5	10·5	27·7	32·3	0·513	27° 50′	21° 50′	17° 00′	29° 50′	29° 40′
6	11·8	35·3	35·1	0·443	35° 10′	24° 15′	17° 40′	22° 20′	22° 50′
7	6·6	29·0	28·9	0·539	28° 40′	14° 00′	12° 50′	37° 20′	36° 20′
8	3·8	26·0	26·2	0·552	25° 30′	8° 00′	8° 50′	36° 00′	33° 50′
9	13·6	32·8	36·0	0·472	33° 00′	28° 20′	24° 40′	21° 50′	23° 30′
Averages		30·7	31·3			18° 30′	15° 50′	29° 35′	29° 15′
Average divergence		±2·0							
Coefficient of correlation						+0·97		+1·00	

No.	Tensile on Initial Cross-section, Normal lb. per sq. inch (a)	Tensile on Initial Cross-section, Bone Dry lb. per sq. inch (b)	Elastic Properties Per cent. Elongation at Rupture, Normal (c)	Elastic Properties Per cent. Elongation at Rupture, Bone Dry (d)	Tensile on Cross-section at Rupture, Normal lb. per sq. inch (e)	Tensile on Cross-section at Rupture, Bone Dry lb. per sq. inch (f)
1	32,700	25,100	25·1	17·5	40,900	29,500
2	35,200	26,200	21·0	14·0	42,600	29,900
3	28,600	22,200	29·8	19·9	37,100	26,600
4	33,700	26,300	22·0	15·3	41,100	30,400
5	31,200	24,500	24·9	16·9	39,000	28,600
6	31,200	25,200	22·3	16·6	38,100	29,400
7	29,300	22,400	28·9	19·0	37,800	26,600
8	30,900	24,800	23·4	15·5	38,100	28,600
9	30,500	24,600	24·0	17·4	37,800	28,900
Coefficient of Correlation	+0·89		+0·97		+0·86	

Coefficients of Correlation of Above with Respect to

(a)	(b)	(c)	(d)	(e)	(f)	
−0·91	−0·90	+0·88	+0·89	−0·89	−0·87	$\sqrt{a_0^2+a_1^2+a_2^2}$
−0·92	−0·92	+0·89	+0·94	−0·87	−0·88	$\cos^{-1} \cos a_0 \cos a_1 \cos a_2$
−0·94	−0·95	+0·94	+0·94	−0·87	−0·91	$\sqrt{(P_0)_A^2+(P_1)_A^2+(P_2)_A^2}$
−0·78	−0·84	+0·85	+0·83			$\sqrt{(P_0)_M^2+(P_1)_M^2+(P_2)_M^2}$

(B) The manufacturing twists per inch $(T_0)_M$, $(T_1)_M$, and $(T_2)_M$, of the single yarn, first ply, and second ply respectively. The last and first were determined by a direct observation; $(T_1)_M$ was obtained by relation (4). Since $(T_0)_M$ is subject to greatest variation in determination due to short length tested, and it was known that only one basic yarn was used, it was thought justifiable to use the average 22·0 for further computations.

(C) $(L_0)_M$, $(L_0)_A$, $(L_1)_M$, and $(L_1)_A$ were obtained by direct observation. It may be computed that the manufacturing size from expression $15N(L_0)_M$ averages 23·0 plus or minus 0·4 averaged from nine observations.

(D) With respect to actual twists, we have from relation (2) $(T_2)_A = (T_2)_M$. $(T_1)_A$ is here evaluated from relation (5); $(T_0)_A$ was obtained from direct observations on 2-in. lengths, while $(T_0)_A$ calculated was obtained from relation (9). These differ to just about the extent that would be expected from variations in $(T_0)_M$ above.

(E) The cotton concentration is obtained by relation (18). This is apt to be greater the heavier the yarn, and is correlated negatively with N (—0·82). N is negatively correlated with the resultant angle of inclination (—0·90) later to be described. Practically this means that the more twist applied in twisting, starting as here from a given yarn 23s, the heavier the cord (greater weight per unit length), and the denser or closer the fibres will lie together. This, of course, would be expected.

(F) The angles of inclination, α_0, α_1, and α_2. α_0 is computed from formula (10) with K arbitrarily assumed at 0·667, α_1 (a) from formula (11) with K arbitrarily assumed at 0·6, α_2 (a) from formula (12) with K arbitrarily assumed at 0·55. α_1 (b) and α_2 (b) were computed from relations (14) and (15) respectively. The checks of α_2 (a) and α_2 (b) are good, but α_1 (a) averages higher than α_1 (b). However, in both cases the coefficients of correlation are high.

(G) The usually specified elastic properties are tensile strength and elongation at rupture. These are given both for a normal and a bone dry type of testing. In addition, tensile strengths are given for estimated cross-section at rupture (by multiplying the usual tensile by 1 plus 0·01 times per cent. elongation at rupture). The coefficients of correlation between both normal and bone dry tests are so good, that it is hard to see from this why two sets of tests should have been commercially employed, the normal by some rubber companies, and the bone dry one by others.

It is desired now to see how these properties line up with twist relations. This may be attacked from the point of view of either mean angle of inclination or twist factor. Necessarily we cannot deal with these angles individually, but must construct a resultant twist or angle of inclination. Unfortunately, we have no *a priori* method of weighting the incidences of these values α_0, α_1, or α_2, or the factors P_0, P_1, or P_2, as the case may be. In the lack of this knowledge, two arbitrary relations of the resultant angle of inclination to individual values will be set up, the first will be a vector sum formula $\sqrt{\alpha_0^2+\alpha_1^2+\alpha_2^2}$, the second will be a trigonometric relation $\cos^{-1} \cos \alpha_0 \cos \alpha_1 \cos \alpha_2$. The merits or demerits of these relations must be for the present judged by their correlations. It will be observed that both these are fairly well correlated with both tensile strength and elongation (average coefficient of correlation 0·9).

In computing the resultant twist factor the vector sum will arbitrarily be used, although a form corresponding to $\cos^{-1} \cos \alpha_0 \cos \alpha_1 \cos \alpha_2$ would be more rational. It will be seen that the correlations of $\sqrt{(P_0)_A^2 + (P_1)_A^2 + (P_2)_A^2}$ are somewhat better than $\sqrt{\alpha_0^2+\alpha_1^2+\alpha_2^2}$. Possibly the explanation of this is that the former do not involve the effect of varying cotton concentrations, while angles of inclination are affected by cotton concentration. In the vicinity of rupture, the lateral compression set up by longitudinal tension would even out the cotton concentrations of different cords, so the effects of this factor are reduced or eliminated.

It is to be noted further, that the corresponding resultant of twist based on manufacturing twists is inferior in correlation to that based on actual

twists, on which account, the latter are to be preferred in explaining the elastic properties of tire cord. This is to be expected, since usually the yarn is twisted right handed, say, 20 or more twists, then the plied yarns are twisted to the left 20 odd twists, while finally the second ply is put in in the same direction as the yarn twist. So the actual structure, although a function of manufacturing twists, is not a simple function.

If we now compare tensile strengths with elongations at rupture, it is found that for normal testing the coefficient of correlation is $-0{\cdot}91$, while for bone dry testing it is $-0{\cdot}95$. The higher the tensile strength the lower the elongation at rupture. As was earlier pointed out, this fact has considerable technical importance. In Fig. 2 is plotted this relation for normal testing on double logarithmic paper, extrapolating towards lower stretch and higher tensile strength. This extrapolated line passes in close vicinity to the elongation at rupture of the cotton fibre as given by Barratt,[4] and the approximate cotton hair tensile as given by Peirce.[5]

Thus the elastic properties of tire cord are necessarily conditioned by the elastic properties of the cotton hair, the initial function of twist and plying being to increase the stretch at the expense of strength as ordinarily determined, though the ultimate function of twist and plying is probably to increase the efficiency of bonding between the fibres with respect to resistance to repeated stressing.

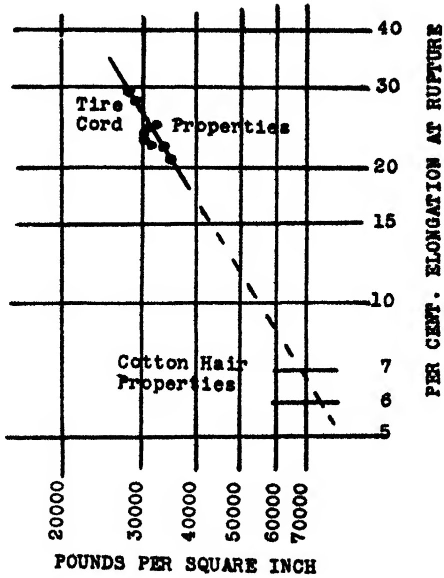

FIG. 2

THE EFFECT OF PLYING

To analyse the development of tensile strength and uniformity with successive plying in tire cord, nine other cords (described by the writers[8]) were subjected to the following investigation. Lengths of single yarn and first ply yarn were removed from these cords without disturbing the actual twists per inch. With these single yarns, and first plied yarns and cords themselves, breaking loads, times of rupture, equivalent number (of broken material from weighed 3-in. ruptured lengths), as well as elongation at rupture, was determined. This procedure is different from that of the usual tire cord tensile strength test. The tensile strengths were further corrected to a 10 second time of rupture by relations developed by Midgley and Peirce.[6]

In all cases the greater the twist or the resultant twist, the greater the extension at rupture and the less the tensile strength, as would be expected, since the twists were all in excess of twist at maximum tensile strength. The point at issue, namely, the effect of plying, can be developed well enough from the averages, even though the twists varied. The average elongations at rupture of single yarns, first plied yarns, and complete cord were 8·8%, 13·5%, and 19·8% respectively. The corresponding tensile strengths were

37,150, 42,820, and 40,600, or in order 100, 115, and 109, based on initial cross-section; but if based on actual cross-section at rupture these would become 40,300, 48,600, and 48,600 respectively, or in order 100, 121, and 121.

The apparent reason for the diminution of tensile from 42,820 to 40,600 is mainly reduction in cross-section at rupture due to greater stretch, although another factor may enter the problem.

The average per cent. variation of breaking load of single yarns, first plied yarns, and tire cord were $\pm 11{\cdot}4\%$, $\pm 5{\cdot}2\%$, and $\pm 2{\cdot}9\%$ respectively. Here we find the variability diminishes as the yarns are plied together, as should be expected. From the laws of probability, it would be expected that the variation in breaks of parallel yarns plied 5 together and plied 15 together (the variation of the single yarn being $\pm 11{\cdot}4\%$) would be $\pm 11{\cdot}4\%/\sqrt{5}$ and $\pm 11{\cdot}4/\sqrt{15}$, or $\pm 5{\cdot}1\%$ and $\pm 2{\cdot}95\%$; and indeed this checks very closely with actual variations $\pm 5{\cdot}2\%$ and $\pm 2{\cdot}9\%$ actually found.

Successive plyings then do increase the stretch and tensile strength at rupture based on actual cross-section at rupture, the latter (tensile strength) approaching a limiting value. Just how much the increase in tensile strength is due to the retaining qualities of plying on one hand and to the diminution in variability on the other hand, cannot be dependably calculated from this data, but both effects undoubtedly do exist.

STRESS-STRAIN CURVES

The elastic properties of materials after multiple stretching are of nearer real technical incidence, still due to time requirements the relation of stress to strain on first stretch is usually studied. Fig. 3 shows the relation of stress in pounds per square inch to per cent. elongation on a normal twist tire cord* (23/5/3s, 4 T.M.—18–8 construction), a cotton yarn of normal twist, worsted, viscose rayon, silk, and linen thread or yarn. It will be seen that with respect to extensibility, the order is essentially that given by Barratt for fibres of linen, silk, cotton, and worsted. At low stress, cotton is more extensible than rayon, but at high stress the reverse is true. This probably follows from the twist in cotton yarn which is greater. The greater stretch at high stress is in main due to greater degree of depolymerisation of the rayon compared with the cotton hair structure. Tire cord is more extensible than cotton yarn at all stresses.

If tire cord stress-strain curves are plotted on double logarithmic paper, the locus is nearly a straight line of such a slope that at any point one part per hundred increase in tension corresponds to a 0·7 parts per hundred increase in elongation. This ratio 0·7 varies somewhat from one cord to another.

Precision researches show that at low stresses this ratio is somewhat higher, while near the vicinity of rupture the ratio may be nearly unity, particularly if the twist is somewhat low.

Although the ratio 0·7 is nearly the same irrespective of twist, the actual elongations, at any stress, increase, either as the actual twists of the single yarn, or the first ply twists, or the second ply twists increase, provided other twists are kept constant. These series of tire cords were designed so that

* Cord constructed by twisting 23s single yarn using 4 twist multiplier right handed, plying 5 such yarns 18 turns per inch left, finally 3 such plied yarns 8 turns per inch right handed.

these relations held. In these stress-strain tests the mean twist factors of single, first plying, and second plying twist were in order 5·6, 4·4, and 7·4 respectively. Respective mean increments of twist factor 0·85, 1·0, and 1·95 produced mean increments in elongation of 6, 3, and 20 parts per hundred. The relative effectiveness of percentage twist factor increment

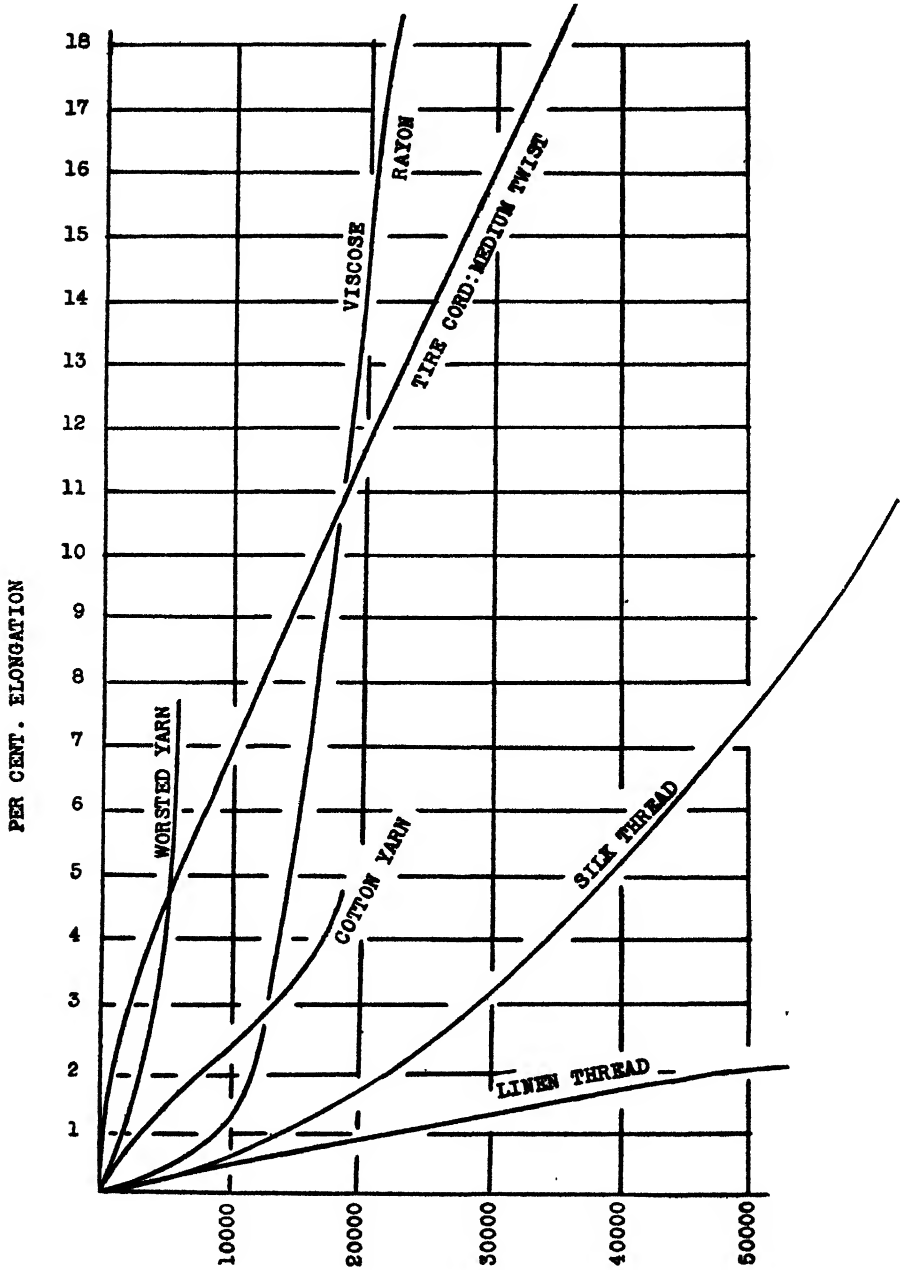

Fig. 3

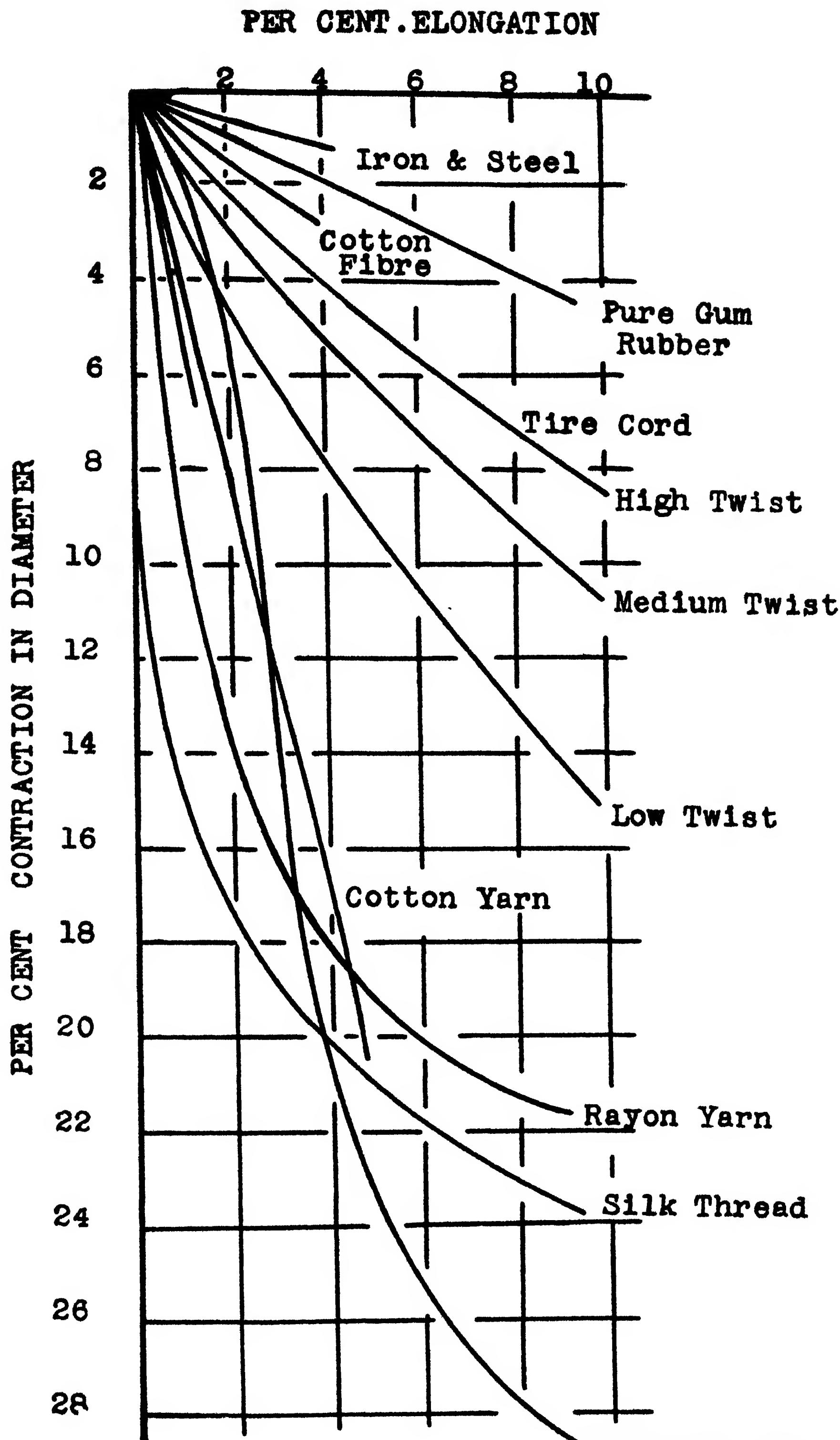
PER CENT.ELONGATION
2
4
6
8
10
Iron & Steel
Cotton Fibre
Pure Gum Rubber
Tire Cord
High Twist
Medium Twist
Low Twist
Cotton Yarn
Rayon Yarn
Silk Thread
Worsted Yarn
PER CENT CONTRACTION IN DIAMETER
2
4
6
8
10
12
14
16
18
20
22
24
26
28

FIG. 4

at these average twist factors are in the ratio 0·4 for single yarn twist, 0·15 for first ply twist, and 0·75 for second ply twist. That is to say, for a given increase in twist factor, the resultant extensibility was most affected by the second ply twist, and least affected by the first ply twist. If the correct ratio of correlation of single, first ply, and second ply twist upon extensibility could be determined, the correlation of individual twists upon the elastic properties of cord could be more accurately expressed and earlier assumed relations might be rationalised.

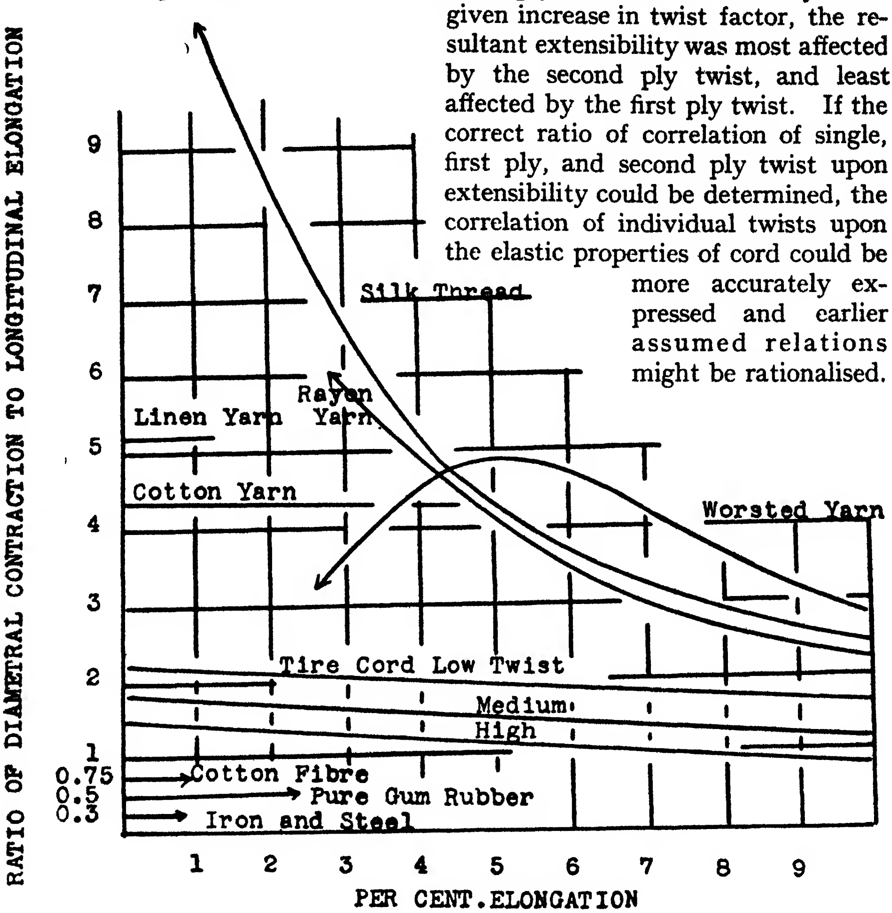

Fig. 5

POISSON RATIO WITH YARNS

As any material is extended in length, the cross-section diminishes. This is true of metals to a degree, but more especially true of porous open structures, such as fabric yarns. To investigate this aspect of yarns and tire cord, a 10-in. rack was devised in which pre-determined and controllable elongations of 2·5%, 5%, 7·5%, and 10% could be applied at the same time the optical diameter (to differentiate from ordinary gauged diameter) could be measured by means of a microscope at equally distributed points along the yarn or cord length.

Figs. 4 and 5 exhibit the relation of longitudinal extension to diametral contraction (or the ratio of these) for the different materials with rubber, steel, and cotton hair material inserted for reference points. It will be seen that this effect is greatest with silk, rayon next, then linen, cotton, worsted, and tire core in order noted (with some reversals). With tire cord, the contraction is less the greater the twist approaching closely the ratio exhibited by the cotton hair.[7]

In the case of low, medium, and high twisted tire cords, the cotton concentrations were in the order 0·44, 0·47, and 0·51 respectively, so it can be seen that the denser structure is least affected by diametral contraction on stretching as would be expected. In these cords the actual single twists were about 29·2 per inch, first ply actual 10 per inch, but second ply twists were 5·6, 8, and 10·4 per inch respectively.

RECOVERABLE ELONGATION: TRUE ELASTIC PROPERTIES

There is a well-known technical testing device employed to illustrate the apparent advantage of cords of different twists or extensibilities. In this device two cords of different extensibilities are stretched imposing equal extensions on both. Usually the less extensible cord shows more sag on releasing the imposed extension. If the device is arranged so that the same load is passed through both cords, usually the reverse is true, and the more extensible will exhibit more sag. Tire cord service is intermediate between an equal loading and an equal extension service, tending toward the latter, the lower the inflation pressure in the tire. This simple test implies a basic recognition on the part of tire designing engineers of the disadvantage of too much set, or an inelastic type of tire cord. An ideal tire cord should, after stretching, come back to its initial length.

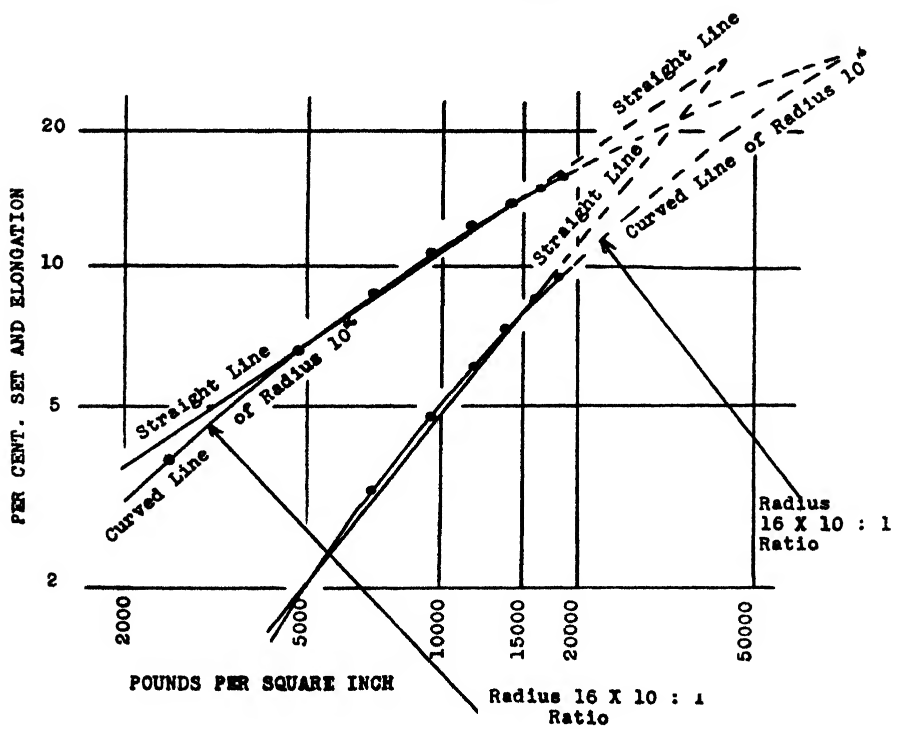

FIG. 6

To standardise this practical test[8] into a systematic procedure, the following was arbitrarily adopted. Black marks were placed one meter apart on tire cords under zero loading. Then the cord was alternately loaded and unloaded, using 5-second durations for both load and unload periods, or 10 seconds per cycle. At the end of the sixth loading period the elongation was read off directly in per cent., while at the end of the sixth

unload period the elongation was read off, and called the per cent. set. On the next minute period, the load was increased by one pound, and this continued up to about 8 or 10 pounds. Stresses for the different loadings were

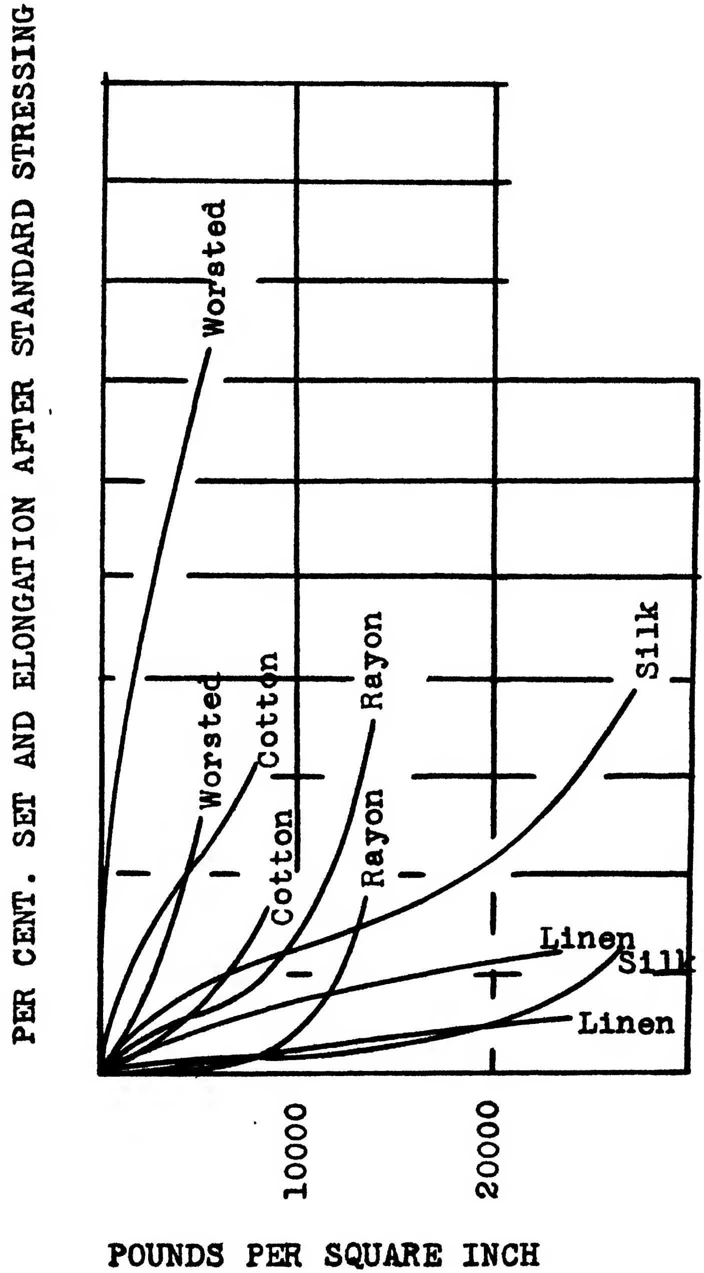

FIG. 7

computed by multiplying N × 1,650 × load in pounds, and both per cents. elongation, and set plotted against loading stresses on either arithmetic or double logarithmic paper. Also the difference between per cent. elongation and set was termed "recoverable" elongation, this also in other plots plotted against loading stresses.

Fig. 6 shows average points from some 100 stress-strain-set tests on a wide variety of tire cords plotted on double logarithmic paper. Both curves are nearly straight lines. If straight lines be passed through the points in the vicinities of 5,000 and 15,000 pounds per square inch, their respective slopes will be about 0·675 for the stress-elongation curves and 1·25 for the stress-set curves. More precisely, however, the actual points fall on a curved line of radius 10 to the 16th power units (that is 16 times the 1 to 10 ratio). If these curved lines are extrapolated beyond region of rupture (say, 30,000 pounds per square inch or less) to intersection, the intersecting stress will be found to be somewhat over 70,000 pounds per square inch or in the vicinity of the tensile strength of the cotton hair.

With perfect elasticity there would exist a zero set at all stresses. The higher the set line with respect to the elongation line, the more imperfect the elasticity. When these lines (extrapolated) coincide, the elasticity is obviously zero.

The above procedure is, of course, arbitrary and can be varied both with respect to the number of cycles 6, or the duration of loading 5 *seconds*. For example, as the duration of loading is altered, keeping the cycles 6 the same, the slopes of the curves remain unaltered, but progress upward by 1/50th for elongation and 1/9th for set as the duration of loading quadruples. If the duration of loading is kept constant and the number of cycles increased, both stress-elongation and stress-set curves move upward, but in such a way as to converge or intercept at the same point when extrapolated.

Fig. 7 shows the stress-strain-set curves of worsted cotton, rayon, silk, and linen threads or yarns when tested in a manner analogous to tire cord.

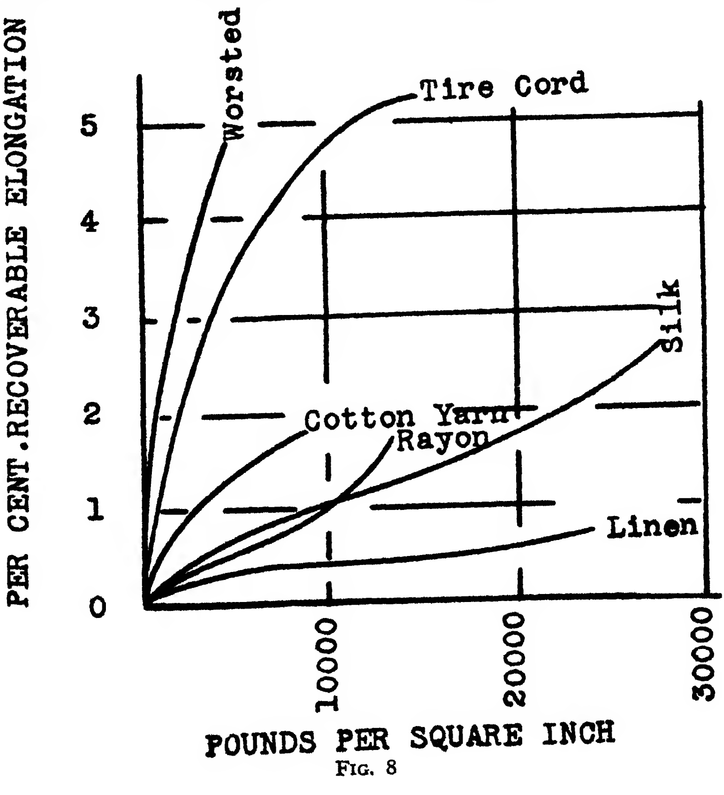

FIG. 8

Usually the higher the elongation at a given stress the higher the set. The next, Fig. 8, exhibits the "recoverable" elongations of these same materials compared with an average tire cord (of 23/5/3s construction, 4·0 T.N.—18–8 manufacturing twists in first and second ply, using $1\frac{1}{16}$ in. cotton). It will be seen that except for worsted, the recoverable strength of cotton yarn is superior to other materials, and tire cord is still superior in recoverable stretch properties to cotton yarn. Both cotton constructions are, of course, superior to worsted in tensile properties.

Fig. 9 exhibits the effect of varying the actual first ply twists, keeping actual single and second ply twist constant upon the "recoverable" elongation of tire cord, while Fig. 10 shows the same thing varying only the second ply twists, keeping other twists constant.

Aeroplane lacing cord is a structure differing from tire cord in that three series of plyings are supplied instead of two. Fig. 11 compares aeroplane lacing cord with tire cord, and with ordinary yarn, showing that for low stresses the more successive plyings, the more extensible. Here, as with tire cords, it has been found that where the extensibility is greater at low stresses, it usually falls off at higher stresses.

INTERCORRELATION OF VARIOUS ELASTIC CONSTANTS OVER A WIDE VARIETY OF CORDS

Twenty-six tire cords were selected to give a wide range of tensile and elastic properties. The cottons ranged from 1 in. plus to $1\frac{5}{16}$ in., constructions from 23/5/3s, 23/4/3s, to 13/3/3s with concomitant variation of resultant

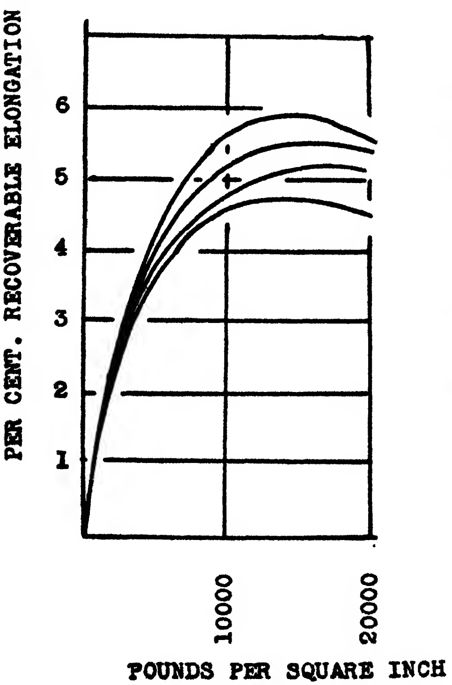

Fig. 9

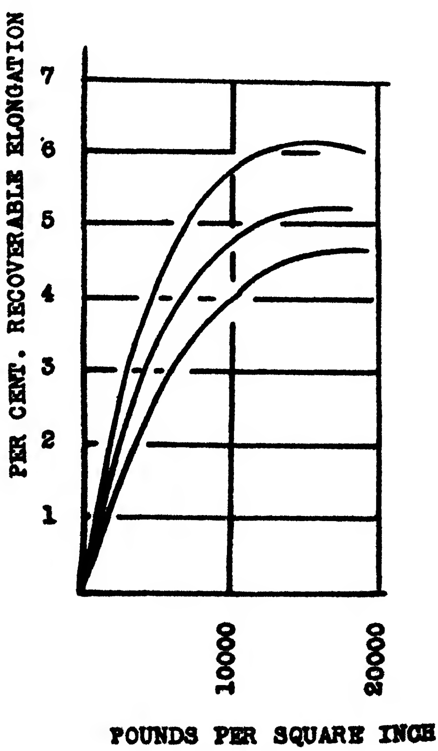

Fig. 10

twists. On these twenty-six materials, ten different tests for elastic properties were applied, and the intercorrelations between each series of tests were worked out. These ten tests were—

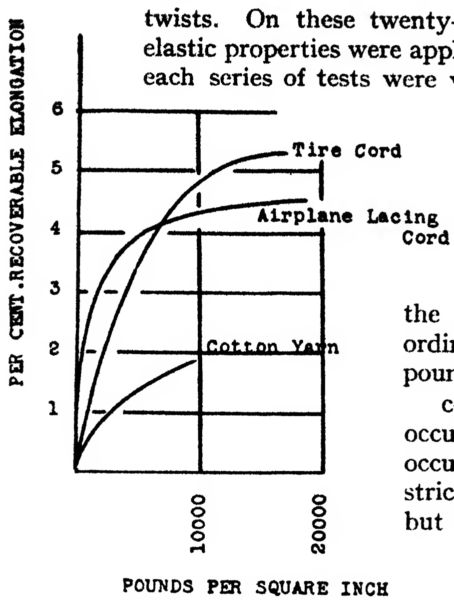

FIG. 11

T—Bone dry tensile at rupture expressed in pounds per square inch of unstressed tire cord cross-section.

η—A strain recovery efficiency obtained from stress-strain-set curves and defined as the ratio of "recoverable" elongation to ordinary or total elongation at 10,000 pounds per square inch.

c—Cotton concentration or ratio of space occupied by cotton fibre to space apparently occupied by cord. This, of course, is not strictly a measure of the elastic properties, but was inserted for special reasons.

T_0—The stress at zero elasticity from stress-strain-set curves, or the stress at the intersection of the curved elongation-set curves.

ne/ns—The mean ratio between 5,000 and 15,000 pounds per square inch stress of slope of stress-elongation to slope of stress-set curve, on double logarithmic paper.

E_0—The common elongation at intersection of extrapolated stress-elongation and stress-set curves.

E—The per cent. elongation at rupture tested bone dry.

E_l—The elongation at 10,000 pounds per square inch from stress-strain-set curves.

E_{MR}—The maximum "recoverable" elongation from stress-strain-set curves. This usually occurs in the vivinity of 15,000 pounds per square inch, but varies somewhat from cord to cord.

E_R—The "recoverable" elongation at 10,000 pounds per square inch from stress-strain-set curves.

Table II exhibits the 45 coefficients of correlation between these different measures of the elastic properties of the 26 tire cords.

From these correlations, it would appear that several groups of measures exist with tensile at one extreme and elongation at the other extreme.

Apparently tensile strength and the efficiency of recovery from equal loading stresses are highly correlated. This is probably why, when cords are stretched with equal loading, the sag is usually greater in the cord possessing more twist and extensibility, although this is reversed when both are subjected to the same extension.

At the other extreme ordinary elongation at rupture, elongation at constant loading, "recoverable" elongation at constant load, and maximum recoverable elongation (at whatever loading it may occur) are also highly correlated, although these as a group are negatively correlated with tensile.

Cotton concentration is very poorly correlated with either tensile strength or elongation. The reasons for this independence are twofold. As has been seen before with the same cotton, the cotton concentration is greater

the greater the twist, which is positively correlated with elongation at rupture. That is, with the same cotton, the greater the twist the greater the extensibility, and the greater the cotton concentration. However, with a variety of cottons, if other things are kept equal, longer and stronger cottons pack together more closely and tend to give higher cotton concentrations. So while for one and the same cotton, cotton concentration is positively correlated with elongation at rupture to a reasonably high degree, it does not hold where both cottons and twists are varied.

The three measures—T_0, ne/ns, and E_0—obtained from the stress-strain-set curves are intermediate between tensile and stretch measures, and T_0 is somewhat nearer to tensile and E_0 is more closely allied to elongation proper, although all are markedly swayed toward elongation.

Table II

Intercorrelation of Properties of Twenty-six Tire Cords of or from Various Cottons, Twists, and Constructions, with Ranges

	T	η	c	T_0	ne/ns	E_0	E	E_T	E_{MK}	E_K
η	+0·9									
c	+0·2	−0·2								
T_0 ...	−0·4	−0·2	−0·4							
ne/ns ...	−0·8	−0·8	+0·1	+0·4						
E_0 ...	−0·9	−0·9	+0·2	+0·3	+0·8					
E	−0·9	−0·9	+0·1	−0·3	+0·8	+0·9				
E_T ...	−0·9	−0·9	−0·1	−0·2	+0·7	+0·9	+0·95			
E_{MK} ...	−0·95	−0·9	+0·2	−0·1	+0·7	+0·9	+0·95	+1·0		
E_K ...	−0·95	−0·9	+0·1	−0·2	+0·7	+0·9	+0·95	+1·0	+1·0	
Average ...	2,9100	58·7%	0·496	66,500	0·561	26·4%	17·04%	10·07%	6·05%	5·80%
Standard deviation	±2,600	5·55%	0·014	11,330	0·034	3·77%	2·26%	2·26%	0·73%	0·815%
Coefficient of variability	·089	·095	·028	·171	·061	·143	·133	·212	·120	·141
Highest ...	34,000	71·0	0·527	93,000	0·637	34·0%	21·6%	13·7%	7·6%	7·4%
Lowest ...	23,800	50·4	0·467	47,000	0·511	18·5%	13·2%	5·9%	4·6%	4·2%

For practical routine testing, it hardly seems advantageous to extend tests much beyond the usual tensile tests and elongation at rupture tests, possibly with addition of stretch at constant load.

Much more preferable, it would seem, would be to standardise upon the basic raw material quality and rigorously controlling manufacturing twists, tensions, humidities, and temperatures. Several years ago this would not have been a feasible means to rubber companies, but now that most rubber tire companies own or control their own tire cord manufacturing facilities, such a control of cotton and structure separately and independently is probably more rational than an attempt to define the goodness of the product resulting from both cotton quality and manufacturing organisation.

Methods whereby cotton quality can better be defined and measured independent of usual manufacturing processing, it is hoped may be partially treated in a later paper.

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31—CRIMP IN WOOL AS A PERIODIC FUNCTION OF TIME

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INTRODUCTION

Although numerous measurements of crimp in wool appear in the literature, as far as we are aware, no attempt has been made up to the present, to relate the total number of crimps in a fibre to fibre length. The results of the measurements described in this paper bring to light a new relationship; namely, that the total number of crimps per fibre, in the fibres of any lock, is constant, and independent of the length of the fibre. Fibre length in the same lock may vary by many centimetres, but the total number of crimps per fibre will be approximately the same, regardless of the actual fibre length.* Exceptions occur with some very short fibres.

In all probability this relationship exists in crimped wool from all pure-bred sheep and is very clearly shown in this study of the Merino.

The work was carried out as a result of recent findings by Roberts[1] correlating fibre length and fibre thickness, and also a very interesting observation made by Mr. Lefroy of Waleburg, W.A.[2] Mr. Lefroy noticed that in a certain lock of wool that had been allowed to grow for twelve months the *number* of crimps produced in each successive period of four months was constant (namely 10), but that the length of wool produced in each period, and consequently the size of the crimp waves, was distinctly variable. It is easy to realise that if such an observation could be proved to be a general rule, we should be led to the inevitable conclusion that crimp formation is a periodic function of time.

EXPERIMENTAL

Method

As it was not practicable to observe the growth of wool on the sheep, locks from fleece wool were studied.† Each of 100 to 200 selected fibres was measured for length (stretched until the crimp waves were just straightened) and its total number of crimps counted. It was found most satisfactory to take the chosen fibres from the lock as a small bunch, that is so that the fibres measured had all been grown in close proximity to one another. The following samples were examined in this way—

(*a*) 13 specimens of Merino fleece wool (from Australia, Tasmania, New Zealand and South Africa.)

(*b*) 2 specimens of New Zealand Romney fleece wool.

(*c*) 4 samples cut from different parts of a Merino specimen skin.

(*d*) 2 specimens of New Zealand crossbred fleece wool.

Experimental data - Merino fleece wools

The measurements are recorded in the accompanying tables and figures.

Table I contains the results obtained from the thirteen Merino samples (*a*). The first column gives the length group, the second the number of fibres occurring in the length group, the third the mean number of crimps per fibre in that length group, and the fourth shows the number of crimps per centimetre (of straightened fibre) calculated by dividing the figures in the third

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* See footnote on p. T485.

† In so doing we necessarily made the seemingly safe assumption that the different fibres in the lock were produced in the same period of time; that is, since the last shearing, and under comparable conditions.

column by the mean length of the fibres in each length group respectively* (see Appendix I). The fifth column contains the arithmetic mean, or average, of the total number of crimps in each fibre (taking into account every fibre measured), column six records the standard deviation from this mean, and the last column the coefficient of variation (or the percentage deviation).

Table I

Analysis of locks of Merino wool for fibre length and number of crimps per fibre

Length** group (cms)	f	Mean number of crimps Per fibre	Mean number of crimps Per cm †	M.‡	S D	Coefficient of Variation
(1) New England Extra Super (Australian), 80's-90's, 100 Fibres						
9·0– 9·5	12	56	6·10	59·4	±6·27	10·54%
9·6–10·0	21	60	6·19			
10·0–10·5	23	60	5·80			
10·6–11·0	12	59	5·54			
11·0–11·5	16	62	5·52			
11·6–12·0	5	61	5·16			
(2) Toise River (Cape), 80's, 100 Fibres						
3·5– 4·0	4	27	7·07	26·5	±1·51	5·71%
4·1– 4·5	50	26	6·12			
4·5– 5·0	38	27	5·68			
5·1– 5·5	7	27	5·14			
(3) High Class (Cape), 64's–70's, 68 Fibres						
9·5–10·0	5	53	5·40	54·8	±3·94	7·18%
10·1–10·5	6	54	5·22			
10·5–11·0	8	56	5·20			
11·1–11·5	19	55	4·91			
11·5–12·0	8	55	4·71			
12·1–12·5	6	55	4·47			
12·5–13·0	5	58	4·68			
(4) Cape Wool—Over 12 Months' Growth, 64's, 347 Fibres§						
8·8– 9·8	25	40	4·33	57·7	±7·88	13·67%
9·8–10·8	25	45	4·39			
10·8–11·8	25	47	4·18			
11·8–12·8	25	54	4·41			
12·8–13·8	17	54	4·08			
13·8–14·8	22	57	4·00			
14·8–15·8	30	61	4·00			
15·8–16·8	30	59·5	3·66			
16·8–17·8	29	63	3·65			
17·8–18·8	32	63	3·45			
18·8–19·8	27	63·5	3·30			
19·8–20·8	25	72‖	3·56			
20·8–21·8	17	66‖	3·11			
21·8–22·8	18	63	2·83			
(5) Graaf-Reinet (Cape), 60's–64's, 115 Fibres						
9 –10	7	45	4·74	44·1	±1·03	2·34%
10·1–11	14	43	4·10			
11·1–12	13	43	3·75			
12·1–13	24	45	3·60			
13·1–14	26	45	3·33			
14·1–15	16	45	3·10			
15·1–16	9	46	2·97			

* In these calculations the mean number of crimps per fibre correct to the first decimal place was used and not the nearest whole number as given in column 3.

Table 1—*continued*

Length** group (cms.)	*f*	Mean number of crimps: Per fibre	Mean number of crimps: Per cm †	M.‡	S.D.	Coefficient of Variation
(6) McLachlan Bros (Cape), 60's–64's, 114 Fibres						
9 –10	6	43	4·53	42·5	±2·76	6·50%
10·1–11	16	42	4·00			
11·1–12	21	43	3·74			
12·1–13	36	43	3·44			
13·1–14	18	43	3·19			
14·1–15	11	43	2·97			
(7) Cape Wool, 60's, 120 Fibres						
6 – 7	5	28	4·31	34 9	±3·65	10·44%
7·1– 8	8	33	4·40			
8·1– 9	13	35	4·12			
9·1–10	49	36	3·79			
10·1–11	34	36	3·43			
11·1–12	8	38	3·31			
(8) New Zealand Wool, 60's, 100 Fibres						
9 –10	7	48	5·05	52·5	±5·39	10·28%
10·1–11	7	49	4·67			
11·1–12	11	50	4·35			
12·1–13	17	53	4·24			
13·1–14	13	52	3·85			
14·1–15	17	55	3·79			
15·1–16	11	55	3·55			
16·1–17	6	56	3·39			
17·1–18	6	55	3·14			
(9) Tasmanian Wool, 60's, 101 Fibres						
9 –10	7	38	4·00	41·1	±2·94	7·16%
10·1–11	25	40	3·81			
11·1–12	23	41	3·57			
12·1–13	24	41	3·28			
13·1–14	16	41	3·04			
(10) Australian Matchings, 58's, 193 Fibres§¶						
7·75– 8·75	6	27	3·27	37·4	±4·24	11·33%
8·76– 9·75	13	30	3·24			
9·76–10·75	8	32	3·12			
10·76–11·75	20	38	3·38			
11·76–12·75	35	40	3·27			
12·76–13·75	23	39	2·94			
13·76–14·75	44	39	2·74			
14·76–15·75	19	38·5	2·52			
15·76–16·75	15	37	2·28			
16·76–17·75	10	38	2·20			
(11) Stud Ram—"Bonnie Sir Charles" (Free State), 104 Fibres (Lock from rump)						
6 – 7	6	17	2·63	18·8	±3·40	18·03%
7·1– 8	49	18	2·45			
8·1– 9	42	20	2·35			
9·1–10	10	19	2·00			

Table 1—*continued*

Length** group (cms.)	*f*	Mean number of crimps		M.‡	S.D.	Coefficient of Variation
		Per fibre	Per cm.†			
		(12) STUD RAM—"JEAN" DALKEITH (AUSTRALIA), 99 FIBRES				
6 – 7	5	29	4·5	41·0	±7·81	19·04%
7·1– 8	7	33	4·4			
8·1– 9	—	—	—			
9·1–10	10	38	4·0			
10·1–11	15	40	3·8			
11·1–12	21	44	3·8			
12·1–13	28	44	3·5			
13·1–14	6	42	3·1			
		(13) STUD RAM—"9–1" (AUSTRALIA), 106 FIBRES				
6 – 7	5	29	4·5	36·1	±7·42	20·59%
7·1– 8	6	31	4·1			
8·1– 9	6	36	4·2			
9·1–10	6	37	3·9			
10·1–11	12	34	3·2			
11·1–12	19	38	3·3			
12·1–13	21	38	3·0			
13·1–14	18	38	2·8			
14·1–15	12	36	2·5			

** Length groups containing less than 5 fibres are omitted
† Per cm. of straightened fibre
‡ Mean number of crimps per fibre, taking into account every fibre measured.
§ Fibres selected from length groups measured by the Dept. of Biology.
|| Classes contained a few fibres with total number of crimps much above the average
¶ Although wools of qualities coarser than 60's are usually not classed as Merino's, this slightly coarser wool is included here to make the range of qualities measured as wide as possible.

The following visual observations on the above wools were made during the measurements and are recorded here for reference—

(1) *New England extra super*—This is a sample of some of the finest wool grown.
(2) *Toise River*—A very short lock.
(3) *High Class Cape*—A very even wool
(4) *Cape Wool,* over 12 months' growth—Lock 12 cms. long, probably about 18 months' growth. Short fibres very fine. The two classes marked || each contained a few fibres with the number of crimps well above the average, and these probably accounted for the high figure obtained for the mean number of crimps per fibre.
(5) *Graaf-Reinet (Cape).* Very good sample.
(6) *McLachlan Bros. (Cape)*—Very good sample.
(8) *New Zealand* 60'*s*—Good sample of wool, does not look like a crossbred. A bit mushy with a harsh appearance, put down as a 60's but probably 64's to 66's Continual variation in the fineness of the fibre is striking; it is coarse at the tip and gets gradually finer towards the root.
(12) *"Jean"*—Very irregular wool. Great variation in number of crimps for fibres of the same length. Thickness of fibres also varies a great deal.
(13) "9–1"—Many fibres of kempy nature. Old sheep. As irregular as the above lock. Some fibres show no crimp.

It is clearly seen from the figures in the first column of the table that the length of the individual fibres from any given lock is by no means constant, the difference in length between the shortest and the longest fibres being never less than 1½ cms. and in some cases as much as 9 cms. The mean total number of crimps in each fibre, however, as shown in column 3, does not

show a corresponding variation*. In some locks the total number of crimps in each fibre is the same whatever the length of the fibre, and with the others it is constant for all but the very short fibres. Apparently, therefore, in the case of these Merino wools the general rule emerges that crimp formation is a periodic function of time irrespective of the length of fibre produced in that time. In other words, adjacent wool follicles on a Merino sheep will, in a given period of time, produce the same number of crimps regardless of the length of fibre grown in that time, and consequently the longer fibres in the lock will have larger crimp waves than the shorter fibres.

The figures in the last column of Table I afford an indication of the comparative degree of uniformity of number of crimps per fibre, within the sample measured. Although, as would be expected with wools from such different sources, there appears to be some variation in the degree of uniformity of the samples, the coefficient of variation exceeds a value of 10·5% in only two cases (Nos. 4 and 10) where it is probably at least partly due to the use of a slightly different method of selection of fibres.†

The results in the first and the third columns of Table I are represented graphically in Figs. 1 and 1a. Since no other factor but total number

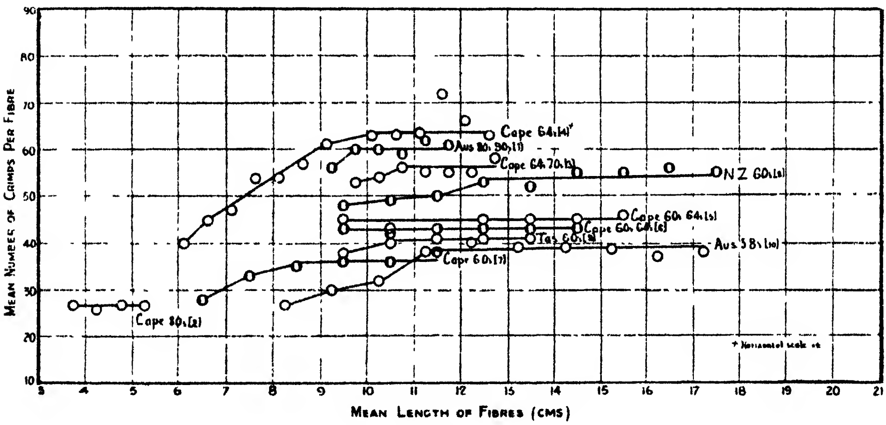

FIG. 1

of crimps is involved in the ordinate (vertical) it follows that straight lines parallel to the x-axis (fibre length) indicate that the number of crimps per fibre is in no way dependent upon or regulated by fibre length, but remains constant. Deviation from the horizontal denotes inconsistency with the general rule formulated above, and, in the case of these Merino wools, occurs only at one end of the horizontal lines (short fibres), being especially marked in the case of No. 4. The reason for the deviation from the rule has not been definitely established. As, however, it is confined to the shortest fibres of the lock, ignoring the possibility of breakage (which seems an unlikely

* It must be pointed out that there is a variation in total number of crimps per fibre in each length group. Thus, each figure in column 3 is a mean of readings which vary by as much as 5 or 6 crimps, or even more than that. However, in each sample, the amount of this variation is found to be fairly constant for every length group. Such variation is in no way whatever related to the length of fibre, but appears to be characteristic of individual follicles. Thus, one follicle may produce n fibres per month, whilst a neighbouring one produces $n+x$ (x being a small number). Measurement of the number of crimps produced by a single follicle in equal periods of time is, of course, the crucial test of the conclusions which are drawn from the existing data.

† In these two cases the fibres measured had not grown in quite such close proximity to one another as those of the other wools.

explanation of the effect) the probability that these fibres either commenced to grow later than the majority of fibres in the lock, or, conversely ceased to grow before the time of shearing, immediately suggests itself. A shorter growth period would, in accordance with the rule, produce a smaller number of crimps.

In this respect sample No. 4 is especially interesting. This was an unusual lock of wool of exceptional length (12 cms.), having been allowed to grow for over 12 months (probably about 18 months). The relationship apparently holds in the case of the longer fibres, but deviation, which is only indicated by a slight slope at one end of the horizontal line with the other samples, is, in this case, very much exaggerated. With such a long growth period it is certainly more questionable, than it is in the case of the other samples, whether all the fibres measured were growing during the same period of time.

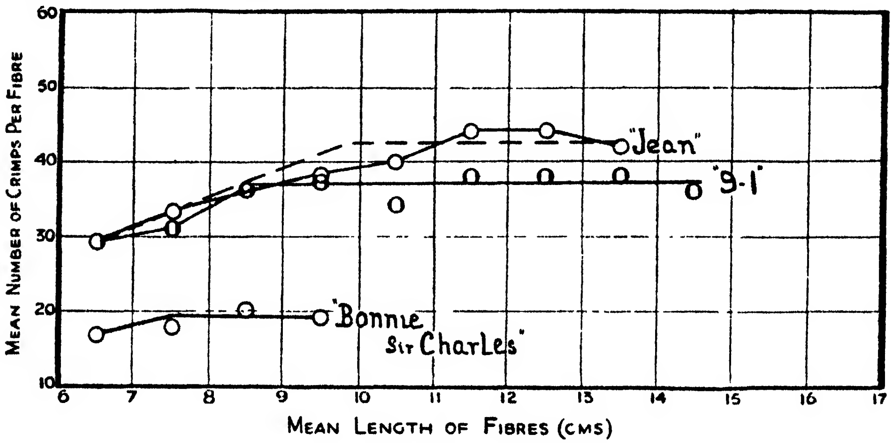

FIG. 1A

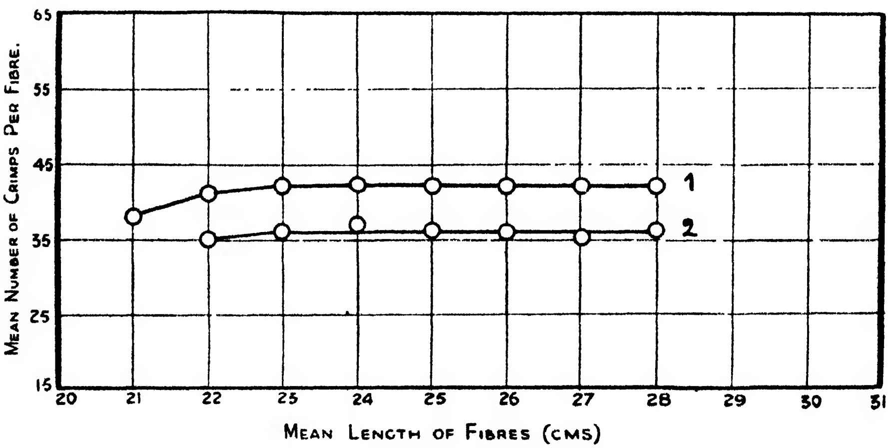

FIG. 2

The sample of wool from the stud ram "Jean" (Fig. 1a) shows more deviation from the rule than do any of the other Merino samples. This was apparently due to the very irregular nature of this wool. Indeed all three samples of wool from the stud rams are far less uniform than the other wools, both with regard to crimp and fibre thickness. (See notes at end of Table I).

A very wide range of wool qualities (90's to 58's) from four different sources has been examined, and from the mass of results obtained it may safely be concluded that the general relationship would hold for any lock of Merino wool taken from a normal, sound fleece.

Romney fleece wool

Two samples of New Zealand Romney wool, kindly provided by Mr. D. J. Sidey, were examined in the same way as the Merino wools. The results are presented in Table II and Figure 2.

Table II

Analysis of New Zealand Romney wool for fibre length and number of crimps per fibre*

Length† group (cms.)	*f*	Mean number of crimps Per fibre	Mean number of crimps Per cm ‡	M.§	S.D.	Coefficient of Variation
(1) Romney Wool (New Zealand), 100 Fibres, 56's Quality						
20·6–21·5	9	38	1·81	41·5	±2·60	6·25%
21·6–22·5	7	41	1·86			
22·6–23·5	5	42	1·83			
23·6–24·5	11	42	1·75			
24·6–25·5	13	42	1·68			
25·6–26·5	19	42	1·62			
26·6–27·5	16	42	1·56			
27·6–28·5	8	42	1·50			
(2) Romney Hogget's Wool (W. Perry, New Zealand), 100 Fibres, 56's Quality						
21·6–22·5	7	35	1·59	35·6	±2·55	7·19%
22·6–23·5	11	36	1·57			
23·6–24·5	7	37	1·54			
24·6–25·5	20	36	1·44			
25·6–26·5	13	36	1·38			
26·6–27·5	18	35	1·30			
27·6–28·5	10	36	1·29			

* Measurements by Miss D. R. Shaw
† Length groups containing less than 5 fibres are omitted
‡ Per cm. of straightened fibre.
§ Mean number of crimps per fibre.

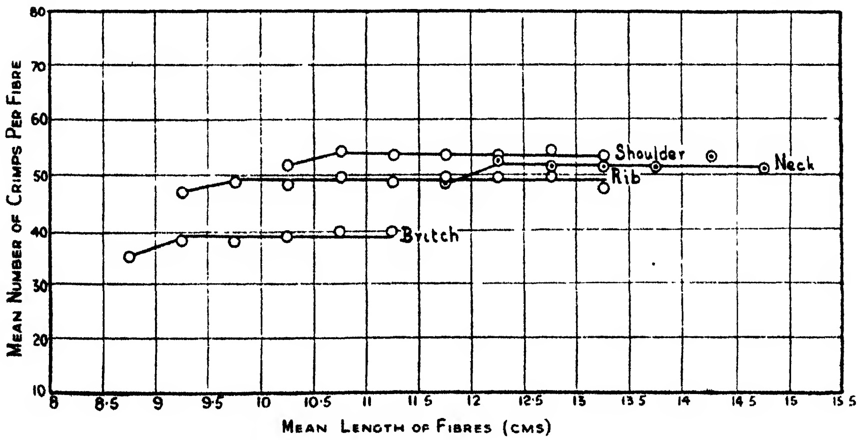

FIG. 3

The relationship is particularly well illustrated by these two samples. Further measurements with pure-bred, crimped wools, other than Merino, are in progress.

Merino wool from specimen skin

On the completion of the above measurements samples of Merino wool, specially cut from definite places on a specimen Merino skin, were similarly examined. The results appear in Table III and Figure 3.

Table III

Analysis for fibre length and crimps per fibre of locks of Merino wool cut from different parts of an Australian Merino specimen skin

Length* group (cms)	f	Mean number of crimps: Per fibre	Mean number of crimps: Per cm †	M.‡	S.D.	Coefficient of Variation
Shoulder Wool—Taken on Shoulder Line and 8½″ from Centre Back Line, 70's, 103 Fibres						
10 –10·5	9	52	5·07			
10·6–11	6	54·5	5·07			
11·1–11·5	11	54	4·80			
11·6–12	21	54	4·60	54·1	±1·93	2·80%
12·1–12·5	29	54	4·41			
12·6–13	18	55	4·31			
13·1–13·5	6	54	4·08			
Rib Wool—Taken 8½″ from Centre Back Line and 12″ from Shoulder Line, 64's, 100 Fibres						
9 – 9·5	5	47	5·08			
9·6–10	15	49	5·03			
10·1–10·5	22	48·5	4·73			
10·6–11	39	50	4·64			
11·1–11·5	56	49	4·36	49·5	±2·57	5·19%
11·6–12	29	50	4·26			
12·1–12·5	23	50	4·08			
12·6–13	6	50	3·92			
13·1–13·5	5	48	3·62			
Neck Wool—Taken 1½″ from Centre Back Line and 12″ from Shoulder Line, 60's to 64's, 102 Fibres						
11·5–12	14	49	4·17			
12·1–12·5	15	53	4·33			
12·6–13	22	52	4·08			
13·1–13·5	23	52	3·92	52·0	±4·20	8·07%
13·6–14	10	52	3·78			
14·1–14·5	5	54	3·79			
14·6–15	3	52	3·53			
Britch Wool—Taken 8½″ from Centre Back Line and 23″ from Shoulder Line, 60's, 200 Fibres						
8·5– 9	5	35	4·00			
9·1– 9·5	16	38	4·11			
9·6–10	33	38	3·90			
10·1–10·5	54	39	3·81	39·1	±3·58	9·15%
10·6–11	47	40	3·72			
11·1–11·5	37	40	3·56			

* Length groups containing less than 5 fibres are omitted.
† Per cm. of straightened fibre.
‡ Mean number of crimps per fibre.

The relationship holds excellently in the case of the shoulder, neck, and rib samples and almost as well with the britch. In every case the length class containing the shortest fibres shows slightly too few crimps as was

noticed with many of the previous Merino samples (see above). All the samples except the britch show the same average total number of crimps per fibre within ± 5% but this average is lower for the britch. The wool is also shorter in this region than in other parts of the body, although (see below) it is apparently not quite so coarse as the neck wool.

A definite conclusion as to the amount of variability in the number of crimps in each fibre, for different parts of the fleece, can only be reached after examination of further skins, but these results are in conformity with expectation. For instance it is not very surprising that the britch wool shows a number of crimps per fibre different from the other samples, for this region of the fleece often yields a very different wool from that of the rest of the fleece.

For purposes of comparison the fineness of the fibres in the different samples was measured and the results are collected in Table IV.

Table IV

Mean cross-sectional area and circularity ratio of fibres from different parts of Australian Merino skin. (The samples were the same as those in Table III.)

Sample	M.*	Mean *ab*† sq. cm.	Coefficient of Variation	Mean *a/b*
Shoulder	54·1	$3{\cdot}35 \times 10^{-6}$	24·19%	1·18
Rib	49·5	3·81	21·18	1·18
Neck	52·0	4·84	22·17	1·18
Britch	39·1	4·28	24·44	1·19

* Mean number of crimps per fibre.

† The number of fibres measured for cross-sectional area was 286, 250, 205, and 256 in the case of the shoulder, rib, neck, and britch samples, respectively.

ab = the product of the major and minor axes of the cross-section of the fibre.

a/b = the circularity ratio.

The method used was that of measuring the cross sectional area of sections of the fibres[3] so that we were also able to calculate the circularity ratio of the cross-sections of the samples. These calculated values appear in column 4. The mean cross-sectional areas of the fibres are given in column 3. The sample of britch wool was found to be slightly finer than the sample from the neck. This may have been partly due to the small region from which the sample was taken, in which case our figures, although giving a true value for the fineness of the samples actually measured for crimp, can perhaps hardly be taken as the true mean fineness of the britch or the neck region of the fleece. However, to find a britch wool finer than the neck wool on the same animal is not unknown and indeed Reimers finds it a general rule. In a recent paper[4] he states—

> ". . . . The wool at the britch of a sheep generally tends to be a little coarser than the wool at the other parts of the body except the neck. The wool at the neck tends to be strictly and distinctly coarser than the wool at the britch."

The increase in mean cross-sectional area between the shoulder sample and the britch sample, as shown in Table IV is about 28%. Table IVa shows the mean cross-sectional areas (calculated from fineness measurements by Roberts' method[5]) of three separate length groups of the lock of 64's Cape wool (see No. 4, Table I) which had previously been measured for crimp. Each of the samples showed an average of 63 crimps per fibre,

but the difference between the fineness of the shortest and the longest fibres is as much as 50%. Thus, in the same lock, the variability in fineness between fibres of different lengths is almost twice as great as the difference in the average fineness of the two samples (taken from shoulder and britch respectively) from the Merino skin above. In spite of this much greater difference however, the average number of crimps per fibre *in the* 64's *lock* remains constant.*

Table IVa

Calculated mean cross-sectional area of fibres from different length groups of Cape 64's wool

Length group (cms.)	M.*	Cms. per mg.	Cross-sectional area *ab* (sq cms.)
21·75–22·75	63	192·51	$3{\cdot}96 \times 10^{-6}$
17·76–18·75	63	274·16	2·79
16·76–17·75	63	289·44	2·64

* Mean number of crimps per fibre

Crossbred fleece wools.

The results obtained from similar examination of crimped crossbred wools appear in Table V and Fig. 4.

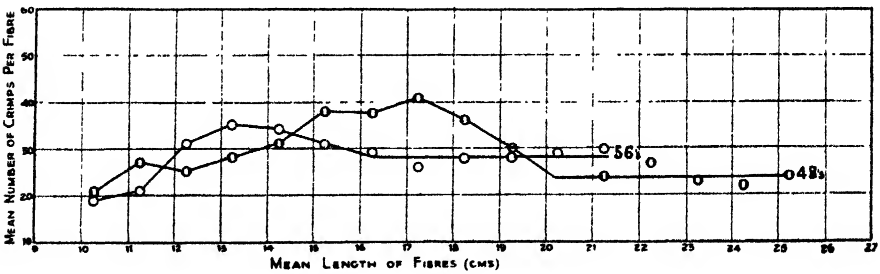

FIG. 4

Although with these samples the wool appeared to be evenly crimped in the lock, separation of individual fibres showed great variation in the size and shape of the crimp waves along a single fibre. So much was this the case that with many fibres it was only possible to estimate the total number of crimps to within an accuracy of three to five crimps instead of to one crimp as with all the previous samples measured.

An indication of the extent of the lack of uniformity in number of crimps per fibre in these samples is given by the figures in the last column of Table V. Whereas the greatest coefficient of variation in the case of the Merino wools was about 10% with these crossbred wools it is 23% and 33% respectively.

A glance at the results is sufficient to show that the relationship which the Merino wools exhibit is not so apparent here. The results are, nevertheless, very interesting. It is clearly seen from Fig. 4 that although the straight line relationship holds in the case of the longer fibres, fibres of intermediate length show a striking abnormality. There is a deviation

* Although Roberts' method of fineness measurement does not strictly permit of accurate conversion to mean cross-sectional area, in this case the accuracy obtainable is quite sufficient to afford a useful means of comparison between the variation in fineness within the 64's sample and that between the different Merino skin wools.

Table V

Analysis of locks of New Zealand crossbred wool for fibre length and number of crimps per fibre.

Length* group (cms.)	f	Mean number of crimps: Per fibre	Mean number of crimps: Per cm.†	M.‡	S.D.	Coefficient of Variation
		CROSSBRED, NEW ZEALAND 56's (I), 100 FIBRES				
12 –13	10	33	2·62			
13·1–14	11	35	2·58			
14·1–15	14	38	2·62			
15·1–16	11	35	2·26			
16·1–17	8	30	1·84	31·5	±7·19	22·81%
17·1–18	10	28	1·59			
18·1–19	8	31	1·68			
19·1–20	7	27	1·38			
20·1–21	9	27	1·31			
		CROSSBRED, NEW ZEALAND 56's (II)§, 326 FIBRES				
·75–10·75	17	19	1·83			
·76–11·75	11	21	1·88			
·76–12·75	34	31	2·49			
·76–13·75	29	35	2·63			
·76–14·75	47	34	2·41			
·76–15·75	41	31	2·03	29·42	±6·80	23·13%
·76–16·75	36	29	1·78			
·76–17·75	29	26	1·53			
·76–18·75	23	28	1·51			
·76–19·75	17	28	1·44			
·76–20·75	31	29	1·44			
·76–21·75	11	30	1·37			
		CROSSBRED, NEW ZEALAND 48's§, 429 FIBRES				
9·75–10·75	28	21	2·05			
10·76–11·75	30	27	2·40			
11·76–12·75	30	25	2·04			
12·76–13·75	30	28	2·11			
13·76–14·75	30	31	2·18			
14·76–15·75	23	38	2·49			
15·76–16·75	23	37·5	2·31			
16·76–17·75	25	41	2·38			
17·76–18·75	30	36	1·97	29·0	±9·93	33·17%
18·76–19·75	28	30	1·56			
19·76–20·75	31	29	1·43			
20·76–21·75	26	24	1·13			
21·76–22·75	27	27	1·21			
22·76–23·75	23	23	0·99			
23·76–24·75	30	22	0·91			
24·76–25·75	15	24	0·95			

* Length groups containing less than 5 fibres are omitted.
† Per cm. of straightened fibre
‡ Mean number of crimps per fibre.
§ Fibres selected from length groups measured by the Dept of Biology.

The following visual observations on the above wools were made during the measurements and are recorded here for reference—

Crossbred, New Zealand 56's—Irregularity in the crimps occurs in the middle classes, in which many more crimps are present than in the longer or shorter fibres, owing to small crimps occurring within the larger crimp waves.

Crossbred, New Zealand 48's—Very great variation in the number of crimps per fibre in all classes. About 4 fibres having a number of crimps greater than 80 were discarded. Size and shape of crimp waves varied considerably along the fibre and in many cases it was impossible to determine the number of crimps with an accuracy of anything more than say ±5 per cent.

from the normal horizontal line at first in an upward direction, then after passing through a flat maximum the curve falls again until it ultimately dips below the level of the horizontal portion of the curve. The portion of the curve above the horizontal line represents fibres which show a greater number of crimps in each fibre than would be expected. On close examination of such individual fibres almost all of them were found to be divided into two definite regions; a very coarse portion with coarse crimp and a very fine portion showing numerous small crimps. However, longer fibres from length groups on the horizontal portion of the curve showed comparatively regular, large crimp waves. It appeared, therefore that the curious form of the fibres of intermediate length must be due to something more fundamental than a mere seasonal effect. The marked difference in the two portions of the fibre suggests a case of incomplete dominance and blended inheritance (as found in the horns of the Merino), the influence of the fine-woolled and coarse-woolled ancestors being traceable in a single fibre. If this is so the "abnormality" is due to the genetic constitution of the follicle itself.

In order to throw further light on the possibility of the truth of such a suggestion, two fibres were selected from the length group 18·75 to 20·75 cms. of the New Zealand 56's sample; that is long, "normal" fibres from the horizontal portion of the curve. Two other fibres were taken from the 13·75 to 15·75 length groups of the same sample, each of which distinctly showed the two definite crimp regions (large and small) referred to above and which fall on the "abnormal" portion of the curve. Each of the four fibres was examined for thickness at even intervals along its length in order to ascertain whether or not the variation in thickness along the fibre length was any more marked in the case of "abnormal" fibres than in the case of the longer "normal" fibres. The measurements were carried out by means of the fibre rotator which has been described elsewhere.[2 and 6]

Measurements of the major and the minor axes of the fibre cross-section were taken at intervals of one cm. along each fibre, and for purposes of comparison the product of these two values (ab), was taken as representing the thickness or cross-sectional area of the fibre. The values thus obtained are presented in Table VI where also are the calculated percentage increases in cross-sectional area, based on the minimum area measured.

Table VI

Variation in thickness of fibres (from tip to root of New Zealand 56's wool).

Distance from tip (cms.)	a*	b*	ab	Increase in ab†	% Increase in ab
Fibres from Length Class 13·75–15·75 cms., Showing 2 Types of Crimp					
Fibre 1					
1	8	11	88	53	151·5
2	8	11	88	53	151·5
3	9	11	99	64	182·8
4	8	12	96	61	174·3
5	8	12	96	61	174·3
6	7	11	77	42	119·9
7	7	10	70	35	100·0
8	7	10	70	35	100·0
9	7	9	63	28	80·0
10	5	7	35	0	0·0
11	6	7	42	7	20·0
12	6	7	42	7	20·0
13	6	11	66	31	88·6

Table VI—*continued*

Distance from tip (cms.)	a*	b*	ab	Increase in ab†	% Increase in ab
			Fibre 2		
1	8	11	88	53	151·5
2	9	11	99	64	182·8
3	8	11	88	53	151·5
4	8	10	80	45	128·5
5	8	10	80	45	128·5
6	7	8	56	21	60·0
7	7	8	56	21	60·0
8	6	8	48	13	37·1
9	6	7	42	7	20·0
10	5	7	35	0	0·0
11	6	6	36	1	2·9
12	7	8	56	21	60·0
13	7	10	70	35	100·0
Fibres from Length Class 18·75–20·75 cms., Showing Even Crimp					
			Fibre 1		
1	11	15	165	75	83·3
2	10	14	140	50	55·5
3	12	14	168	78	86·4
4	12	12	144	54	60·0
5	12	14	168	78	86·4
6	12	14	168	78	86·4
7	11	14	154	64	71·1
8	11	14	154	64	71·1
9	10	14	140	50	55·5
10	10	14	140	50	55·5
11	12	12	144	54	60·0
12	10	12	120	30	33·3
13	11	12	132	42	46·6
14	10	11	110	20	22·2
15	10	11	110	20	22·2
16	9	12	108	18	20·0
17	9	10	90	0	0·0
18	10	12	120	30	33·3
19	10	12	120	30	33·3
			Fibre 2		
1	10	12	120	57	90·5
2	10	14	140	77	122·3
3	10	11	110	47	74·6
4	10	12	120	57	90·5
5	10	12	120	57	90·5
6	12	9	108	45	71·4
7	12	10	120	57	90·5
8	9	12	108	45	71·4
9	9	11	99	36	57·2
10	9	11	99	36	57·2
11	9	10	90	27	43·9
12	7	9	63	0	0·0
13	9	8	72	9	14·3
14	10	7	70	7	11·1
15	10	8	80	17	27·0
16	10	8	80	17	27·0
17	10	9	90	27	43·9
18	10	9	90	27	43·9
19	11	9	99	36	57·2

* In arbitrary units.
† Based on the minimum value of ab.
Note—a and b are the minor and major axes of the cross-sectional area; ab is taken as the cross-sectional area.

The results are represented graphically in Fig. 5 where percentage increase in cross-sectional area is plotted against the distance (from the tip) along the fibre. The heavy lines represent the fibres showing two kinds of crimp in the same fibre, and the lighter lines the fibres with even crimp. As the longer fibres were coarser than the shorter ones the percentage increase in *ab* affords a true means of comparison between them. It is clearly seen

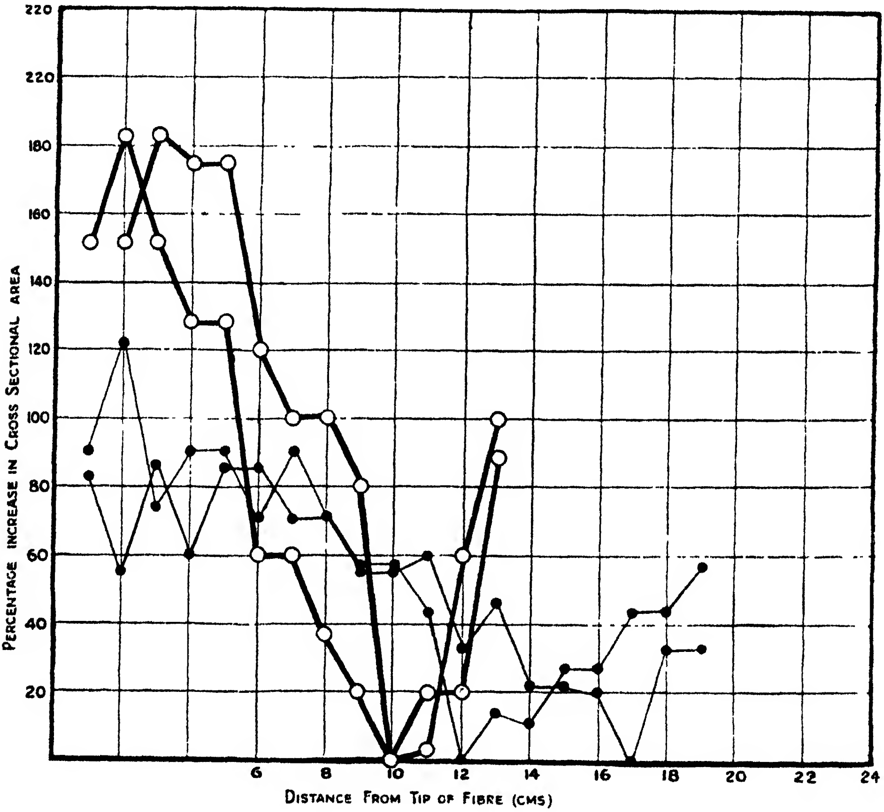

Fig 5

that both the fibres with "normal" crimp show a general decrease in the thickness of the fibre from tip to root, followed after the minimum is reached, by a less, but definite, increase. The fibres showing two types of crimp show the same general effect but to a much more marked extent. Variation in thickness of fibres with conditions of environment is common, drought, or other adverse conditions being marked by a fine region in the fibre. Such an explanation would account for the shape of the curves for the longer fibres, but the exaggerated effect shown in the shorter fibres which grew in the same lock, and therefore under identical environmental conditions, strongly suggests that the effect must be at least partly due to something more fundamental than conditions of environment and is in all probability of genetic origin.

In Fig. 5a a rough comparison is drawn between the position of the maximum and minimum percentage increase in thickness in the two kinds of fibres. For this purpose a mean curve was plotted for each of the pairs of curves in Fig. 5, and further the scale along the abscissæ for each of the two curves was different, and so arranged that the horizontal length of the diagram in each case represented the total fibre length. By such an arrangement, since the two kinds of fibres grew in the same period of time, these curves are directly comparable. It is interesting to note that each type of fibre shows the most robust region near the tip end, corresponding with a period soon after shearing, and the thinnest region during a period of growth shortly before the next shearing. This observation is in agreement with the recent findings of Hardy and Tennyson.[7] It also affords a good example of differential growth within the same lock, the variations in thickness of the fibre along its length, due to the condition of the animal, being similarly reflected in both types of fibre.

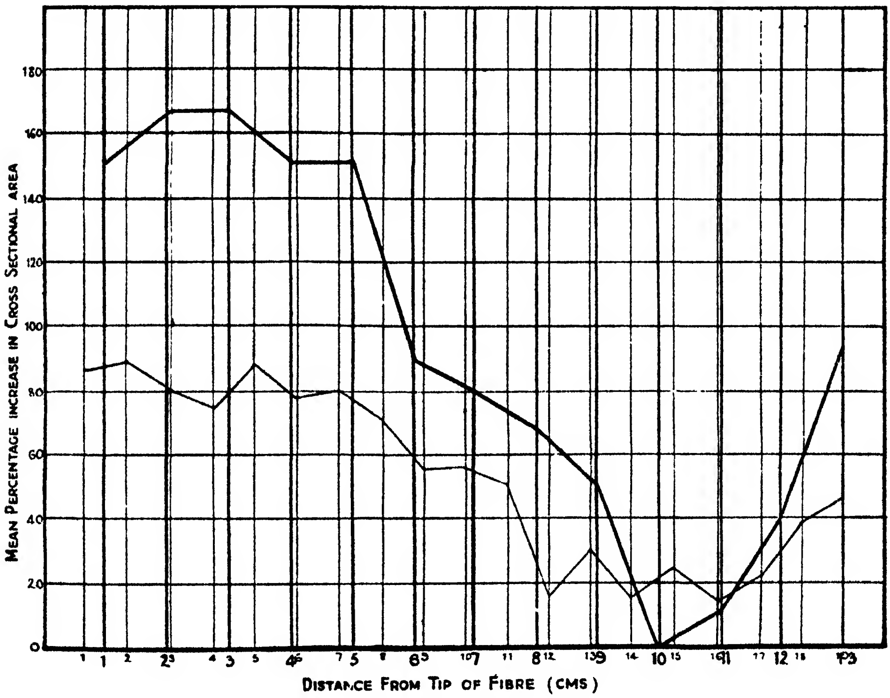

FIG. 5A

Clearly the lack of complete conformity to the relationship with these crossbred wools is of an entirely different character from the slight deviation found in some of the Merino wools. With the Merino the deviation only occurred with short fibres and it was suggested that it might be due to those fibres having been produced in a shorter growth period than the others. In the case of the crossbreds such an explanation would not apply, both because fibres of intermediate length show the greatest divergence and also because the number of crimps in this case is too many and not too few as in the case of the short Merino fibres. Further, Fig. 5a indicates that both types of fibre were probably growing continuously throughout the entire year.

In discussing any divergence from the general applicability of the relationship, it is well to bear in mind that, owing to the method of measurement, seemingly discordant results, although showing that adjacent follicles do not produce the same number of crimps in the same period of time, still do not preclude the possibility of crimp formation being a definite function of time, irrespective of rate of growth, for each individual follicle. Having no facilities for the observation of the rate of growth of individual fibres we were unable to test such a possibility.

Affinity of crossbred fibres for dyestuffs

Preliminary experiments to test the relative affinities for dyestuffs of the fibres in a lock of the crossbred wool, were undertaken by Mr. H. R. Hirst of the Technical Department. The dyeing was carried out in a modified form of the apparatus of Krais and Schleber[8] whereby the samples of wool are held stationary in a tube and the dye solution circulated through them. Accurate comparison is thereby possible. Small bundles of the long "normal" fibres, and of "abnormal" fibres of intermediate length were dyed at the same time in the same dye bath. A distinct difference was noticed in the colour of the two bundles after dyeing, the "normal" fibres absorbed more colour than the "abnormal" fibres (i.e. those that showed coarse and fine crimps in the same fibre). Since the affinity of fibres for dyestuffs (that is, the rate of absorption) is a function of the chemical constitution of the fibres, it appears from this experiment also that the two types of fibres in the same lock are fundamentally different. Further work in this direction is being carried out on other types of wool and on wool which has been grown under various conditions.

Correlation of results with previous work

It is interesting to correlate the results here presented with those obtained in our previous paper on the measurement of crimp.[2] Roberts[1] has found that in the lock there is a general direct relationship between thickness and fibre length. It is found in the present communication that the longer fibres have the same number of crimps as the shorter ones, and consequently, the number of crimps per (unstretched) cm. is probably less in the case of the longer (thicker) fibres, which is the conclusion reached in our previous paper; namely, $k = nd^2$ (where n is the number of crimps per (unstretched) inch and d^2 is the cross sectional area). Further, this general conclusion that the shorter, finer fibres have smaller crimp waves than the longer, thicker fibres is to be expected because, as is well known, the wool sorter bases his sorting partly on this assumption.

Crimp formation and environment

A subsidiary, but interesting conclusion that emerges from the present work, and particularly from the original observation of Mr. Lefroy, is that, unlike fibre length and fineness, the number of crimps produced in a given period of time is apparently independent of environmental conditions. A certain period with adverse conditions will produce a shorter, finer length of fibre than the same period with favourable conditions but the *number*, though not the size, of crimps produced in each period should be identical.

Our thanks are due to Dr. S. G. Barker, Director of Research, for suggesting this problem and for the interest with which he has followed it; to Mr. J. A. F. Roberts, of the Department of Biology, for co-operation in some of

the measurements, supply of samples of wool, and helpful discussion during the course of the work; and to Mr. C. G. Winson, of the Wool Measurement Department, for assistance in the measurement of the fineness of the Merino skin wool.

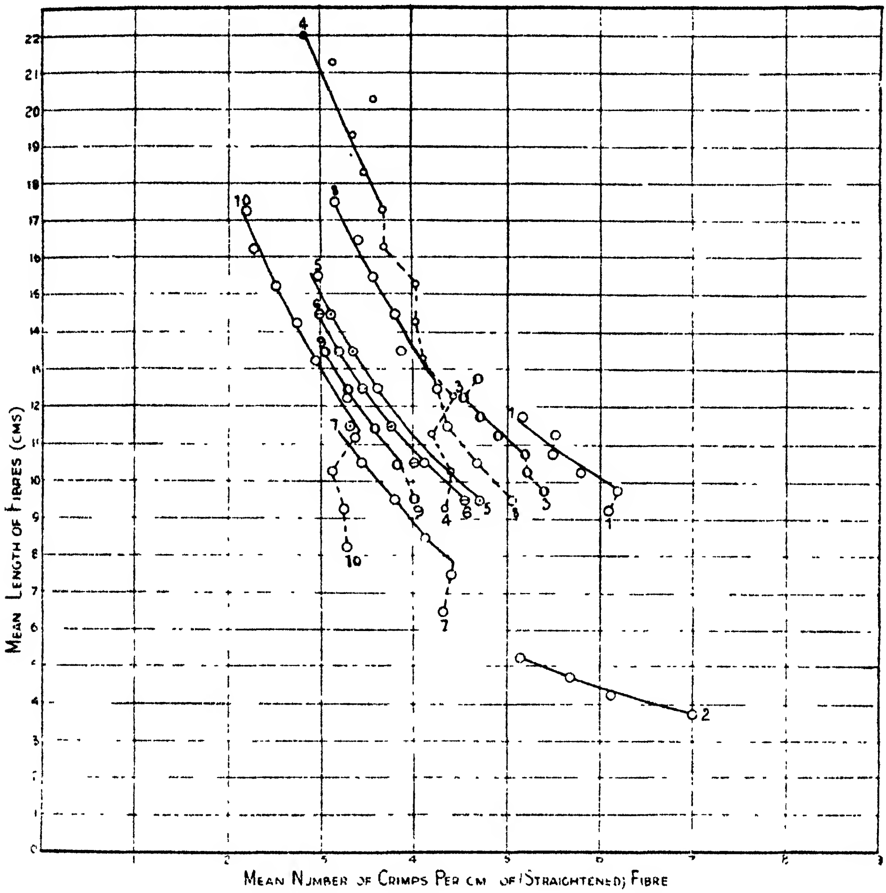

Fig. 6

SUMMARY

(1) The lengths of the fibres in a lock of wool and the number of crimps in each fibre have been measured in samples of Merino wool of widely different qualities and from various sources.

(2) The number of crimps per fibre, in each lock, is found to be entirely independent of fibre length, and remains approximately constant for fibres of all lengths (except the very shortest).

(3) It is concluded, therefore, that in the case of Merino wool, crimp formation is a periodic function of time and is independent of the rate of growth of the fibre.

(4) Two samples of New Zealand Romney wool, examined in the same way, illustrated the relationship quite as well as the Merino samples.

(5) Measurements of samples of Merino wool cut from a specimen skin showed the variation in the mean number of crimps per fibre of samples taken from the shoulder, ribs, and neck to be less than $\pm 5\%$, but the number at the britch was about 15% less than at the shoulder.

(6) Two crossbred wools obeyed the rule in the case of the longer fibres, but fibres of intermediate length showed a striking abnormality which appears to be due to the genetic constitution of the follicles.

APPENDIX

The graphs in the text have been constructed by plotting the mean of the actual figures obtained from our measurements. A slightly less direct method of expressing the results is by calculating the number of crimps per cm. (of straightened fibre) and plotting the resulting numbers against the mean length of the fibre. These numbers appear in the 4th column of Table I and are plotted in Fig. 6. Where the number of crimps per fibre is constant and independent of the length of the fibre, the points will lie on a portion of a rectangular hyperbola asymptotic to the x and y axes, since $xy = k$.

The necessary figures for the similar plotting of the results contained in the other tables have been included in the tables but the graphs have not been constructed.

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[8] Krais and Schleber, Leipziger Monatschrift f. Textil-Industrie 1929, **44**, 211.

CORRIGENDA

7—STATISTICAL METHODS IN TEXTILE RESEARCH. THE ANALYSIS OF COMPLEX VARIATIONS

By H. C. Tippett M.Sc.
(British Cotton Industry Research Association)

By inadvertence errors occurred on page T113 of the March issue. In Table VI, the column under "Weaver D" should read, from the sixth row downwards—

867·8
911·4
875·2
874·0
867·4
888·6
900·0

instead of 888·6, etc., as printed.

28—THE LIABILITY OF DYED WOOL TO MILDEW WITH SPECIAL REFERENCE TO THE RESISTANCE RESULTING FROM CHROMING

By R. Burgess, M.Sc.

It is regretted that by oversight it was not indicated that this contribution, which appeared in our September issue, was received from the Wool Industries Research Association, Leeds.

32—THE MOISTURE RELATIONS OF COTTON
vii—A STUDY OF HYSTERESIS

By Alexander Robert Urquhart, D.Sc. and Norman Eckersall
(The British Cotton Industry Research Association)

INTRODUCTION AND SUMMARY

In the previous papers of this series [5,8,9,10,11,12] it has repeatedly been shown that the moisture regain of a sample of cotton at a given temperature and humidity depends on the previous history of the sample, and this phenomenon of hysteresis has recently been discussed[6,7] with relation to the structure of gels in general and cotton cellulose in particular. It is the purpose of the present paper to describe the investigation of some aspects of the phenomenon that have hitherto been either ignored or merely mentioned.

In the first place it is shown that the absorption and desorption curves are merely the boundaries of an equilibrium area, any point on which may be capable of representing the moisture regain of a sample of cotton under suitable conditions of humidity and prehistory. This fact has some important implications in connection with textile testing; thus fixing the temperature and relative humidity at constant values may not be sufficient to ensure comparable conditions, and additional precautions may have to be taken if large differences of prehistory are possible.

Secondly, it has been found that the desorption curve above 80% relative humidity is itself indefinite, in that it varies with the amount of water previously in the cotton at the saturation point. A definite curve can, however, be obtained by removing water from cotton containing at least 40% of water. This aspect of the phenomenon is perhaps more interesting from the theoretical than from the practical point of view, but it has to be considered when comparisons at high humidities are being made.

Lastly, cotton taken direct from the boll, or while still wet after kier-boiling or mercerising, has been found to have an exceptionally high adsorptive capacity. This is almost certainly accompanied by a high degree of swelling of the cotton; such a condition is often desirable in technical processes, and the results indicate one way in which improvement of these processes might be sought (see page T510).

EXPERIMENTAL METHODS

The experimental methods used in the measurement of the adsorption of water by cotton have already been fully described.[9,11] In the investigations recorded in this paper, the vacuum and desiccator methods were both used, and the usual procedure was followed except in the preparation of some of the bulbs for the vacuum experiments. It was necessary to begin some of these experiments with the cotton at a predetermined moisture content, so that a method of evacuating the bulb without drying it was sought. This was readily accomplished by including in the pumping system two specially blown glass bulbs, each of about six and a half litres capacity. This large volume was evacuated, and the adsorption bulb was opened to it for a few seconds only. As the volume of the bulb was usually about 80 c.c., the pressure of the air in it was reduced to about 0·001 mm. after three or four repetitions of this process, while the amount of water lost rarely exceeded 5% of that originally present. Occasionally, also, it was desired to start

an experiment with the cotton wet; this was done by evacuating the bulb through a large phosphorus pentoxide tube, which could be removed for weighing, and which was designed for easy refilling. This procedure, of course, removed a large amount of water, so that a sufficient excess had to be present originally to ensure that the cotton was still wet when the evacuation was completed.

As before, the temperature of the vacuum experiments was 25° C., and that of the desiccator experiments 20° C.

RESULTS AND DISCUSSION

In the previous work the relation between the amount of water adsorbed and the relative vapour pressure has been expressed by means of two curves, one of which was obtained by adding water to dry cotton until the vapour pressure reached the saturation value, the other by removing water from this saturated cotton until it was once more dry. The earlier work of Rakovski[4] suggested, however, that points lying between these curves might be capable of representing equilibrium conditions; this view has now been investigated more fully.

Two sets of data are available, the materials used being a raw Sakel cotton, in the form of card sliver, and the same cotton after a normal kier boil. The kier-boiled sample was taken immediately after washing and it was allowed to become air-dry at room temperature. Two bulbs were filled with the raw cotton, and the evacuation was effected by means of the large bulbs, so that the experiments were begun with the cotton containing approximately the amount of water corresponding to a day's exposure to the atmosphere of the laboratory. The following curves were then determined, in the order given—

Bulb A—Intermediate desorption curve, intermediate absorption curve, intermediate desorption curve. The cotton was then dried out and absorption and desorption curves were determined in the usual way.

Bulb B—Intermediate absorption curve, intermediate desorption curve, intermediate absorption curve, and desorption curve from the highest point of the previous curve. The cotton was then dried out and two points on the standard absorption curve were determined. These fell on the absorption curve already obtained with Bulb A, and the experiment was discontinued.

It is convenient to use the expressions "standard absorption curve" and "standard desorption curve" in the senses of "absorption curve from dryness" and "desorption curve from saturation." So used, however, "standard desorption curve" can be applied only loosely to a curve obtained for a raw cotton, owing to the indefiniteness of the saturation value of material that contains appreciable amounts of water-soluble substances. In fact, only the lower portion of the desorption curve for the raw cotton (Fig. 1) can be regarded as the standard desorption curve. The failure to reach any definite saturation value is doubtless responsible for the slightly different courses at high humidities of the curves for bulbs A and B; thus the highest values of α reached with the two bulbs were 0·1945 and 0·2005 respectively, and previous experiments by the desiccator method[8] have shown that much higher values are possible.

For the soda-boiled cotton three bulbs were used; in one the cotton was dried initially to provide data for the standard absorption and desorption curves, while the other two were used to determine intermediate curves.

The results for the raw cotton are given in Table I and Fig. 1, and those for the soda-boiled in Table II and Fig. 2. (The soda-boiled cotton was also used in another investigation, to be recorded below. As this second investigation was undertaken at a considerably later date, the standard absorption and desorption curves were redetermined, with bulb H. The same curves were obtained, so the data from both bulbs are included in Table II.) As has been customary in this work, the results are expressed in terms of the relative vapour pressure, p/P, and the weight of water adsorbed by one gram of dry cotton, α; these figures may be converted to per cent. relative humidity and per cent. moisture regain by multiplying by 100.

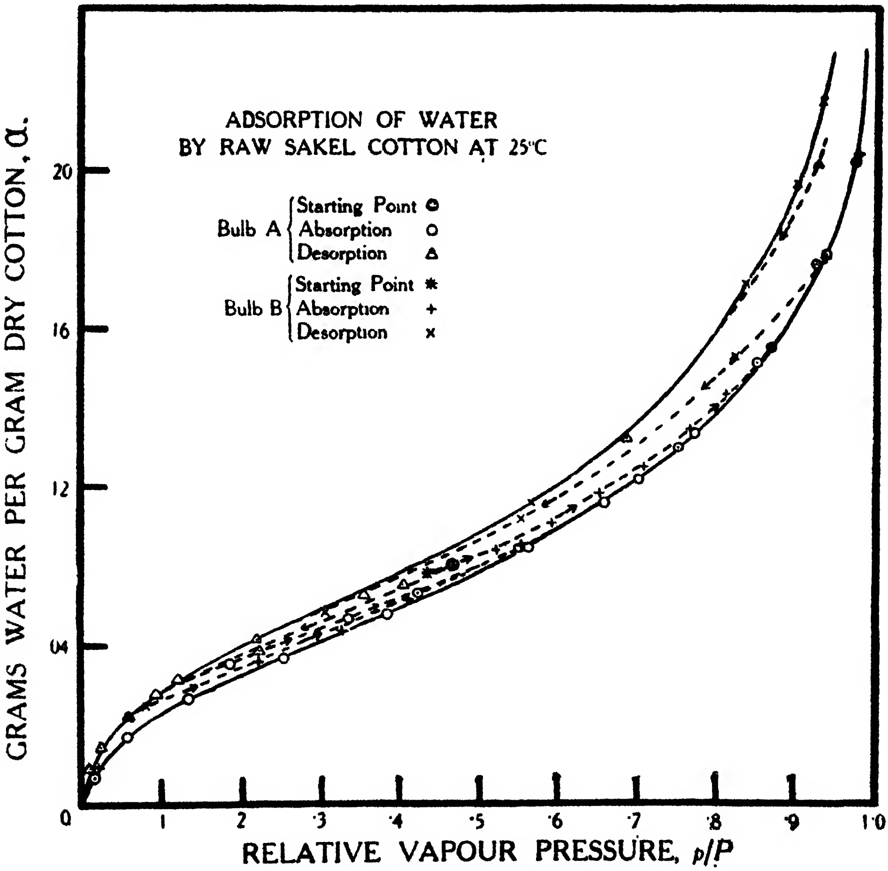


FIG. 1

It is evident from Figs. 1 and 2 that hysteresis cycles that do not extend to zero or saturation pressure lie within the area defined by the standard absorption and desorption curves, and it seems highly probable that any point on that area is capable of representing the amount of water in cotton under appropriate conditions of humidity and prehistory. There is little to be gained by discussing the cause of this behaviour, for it is intimately connected with the general phenomenon of hysteresis, an explanation of which has already been suggested.[7] From this explanation the existence of intermediate curves would indeed be expected, but this is not evidence in favour of that explanation, for it is difficult to envisage any explanation of the difference between the amounts of water adsorbed at a given humidity

Table I

The Adsorption of Water by Raw Sakel Cotton at 25° C. (Vacuum Method)

Bulb A: Order of Determination	Absorption or Desorption	p/P	a	Bulb B: Order of Determination	Absorption or Desorption	p/P	a
1	?	0·463	0·0602	1	?	0·433	0·0585
2	D	·404	·0550	2	A	·521	·0642
3	D	·221	·0383	3	A	·592	·0712
4	D	·092	·0274	4	A	·651	·0782
				5	A	·708	·0852
5	A	·183	·0349	6	A	·766	·0945
6	A	·333	·0465	7	A	·812	·1034
7	A	·420	·0533	8	A	·870	·1146
8	A	·549	·0645	9	A	·938	·1376
9	A	·658	·0760				
10	A	·749	·0901	10	D	·821	·1128
11	A	·850	·1114	11	D	·552	·0719
12	A	·938	·1390	12	D	·080	·0245
13	D	·353	·0524	13	A	·219	·0354
14	D	·217	·0411	14	A	·410	·0518
15	D	·120	·0308	15	A	·553	·0653
16	D	·009	·0087	16	A	·979	·1640
Cotton dried out				17	A	* ?	·2005
17	A	·014	·0064				
18	A	·055	·0166	18	D	·933	·1772
19	A	·132	·0258	19	D	·901	·1559
20	A	·251	·0360	20	D	·835	·1310
21	A	·386	·0476	21	D	·565	·0761
22	A	·561	·0646	22	D	·303	·0480
23	A	·700	·0818	23	D	·056	·0215
24	A	·771	·0933	Cotton dried out			
25	A	·868	·1152	24	A	·018	·0090
26	A	·924	·1359	25	A	·325	·0435
27	A	·974	·1618				
28	A	* ?	·1945				
29	D	·926	·1614				
30	D	·685	·0922				
31	D	·057	·0221				
32	D	·021	·0142				

*Pressure very variable.

Table II

Adsorption of Water by Soda-boiled Sakel Cotton at 25° C. (Vacuum Method)

Bulbs C and H: p/P	a	Bulb D: p/P	a	Bulb E: p/P	a
0·013	0·0041	0·513	0·0693	0·556	0·0730
·057	·0137	·624	·0802	·467	·0638
·159	·0253	·789	·1014	·336	·0499
·306	·0369	·860	·1226	·185	·0338
·383	·0448	·915	·1438	·065	·0195
·516	·0563	·951	·1667		
·698	·0763			·153	·0263
·861	·1056	·881	·1397	·349	·0433
·975	·1786	·827	·1166	·566	·0623
·992	·2036	·613	·0803	·784	·0908
·995	·2182	·089	·0226	·865	·1095
1·000	·2391*	·040	·0152	·938	·1377
				·977	·1720
0·963	·2026			·996	·2057
·932	·1768			1·000	·2264
·917	·1683				
·900	·1562				
·789	·1204				
·748	·1090				
·640	·0851				
·485	·0667				
·164	·0308				
·040	·0156				

*Condensed water in bulb.

after drying and after wetting that does not necessarily include the possibility of intermediate values after less extreme differences of prehistory.

Now since the adsorption isotherm is an area it is important to have some knowledge of the curves that define that area. There is little difficulty about the lower limit; the absorption curve from dryness is obviously the locus of minimum moisture contents for any given material. The exact definition of the upper limit is not quite so easy. In the isotherms previously obtained[7,8] there is no apparent tendency for the hysteresis loop to close at the saturation value; indeed, an isotherm at 40° C. shows quite definitely a point on the desorption curve where the pressure is less than the saturation pressure, but the amount of water present is greater than the absorption saturation value. This effect has now been investigated in greater detail.

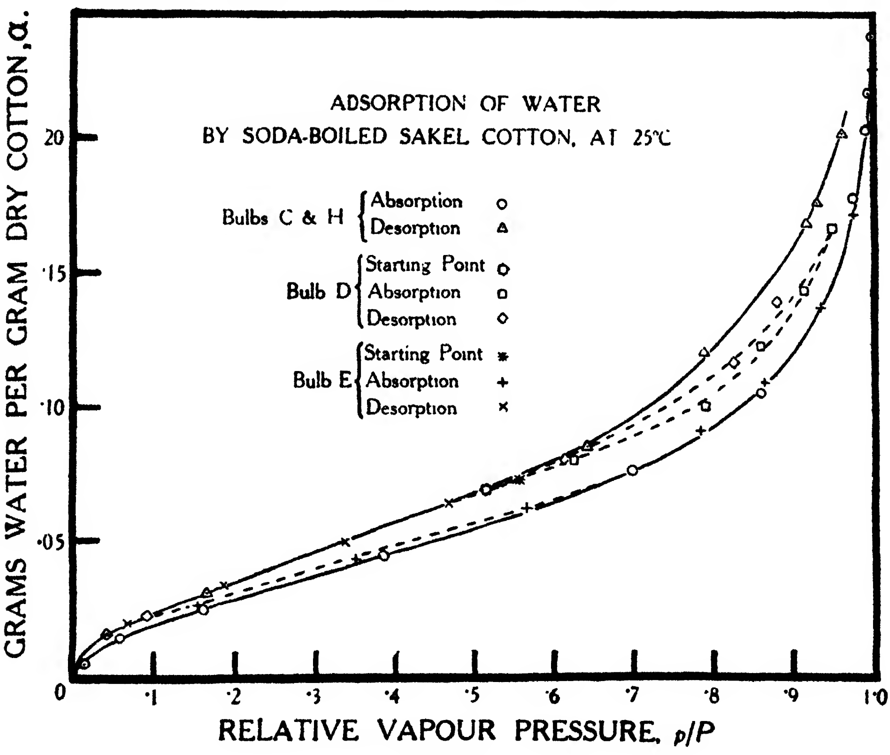


FIG. 2

Two sets of data are again available. The material used in the first was the soda-boiled American cotton 85R, the standard curves of which have been reproduced in a previous paper.[8] With one bulb (F) the absorption and desorption curves were redetermined, but the tap to the water-tube was left open for a long time at the saturation point, so that the amount of water added to the cotton in excess of the saturation value was greater than previously. (Theoretically there is no reason why water in excess of the saturation amount should evaporate from the water tube to the cotton; actually if the tap is left open for a sufficient length of time it is always possible to overstep the saturation value to some extent, probably owing to minute and varying temperature differences between the different parts of the apparatus.) In bulb G was placed a sample of this material that had been steeped in water and squeezed out, in order to provide data for

a desorption curve from the wet condition. The results are given in Table III, and the curves are reproduced in Fig. 3 along with those previously obtained for the same material.

Table III

Adsorption of Water by Soda-boiled Cotton 85R at 25° C.

Bulb F p/P	Bulb F a			Bulb G p/P	Bulb G a
0·013	0·0077	...	...	1·000	0·6398*
·132	·0242	...	...	1·000	·4027
·325	·0405	...	...	0·984	·2919
·535	·0568	...	...	·972	·2495
·701	·0732	...	...	·936	·1922
·972	·1640	..	...	·896	·1598
·985	·1841	..	...	·787	·1146
·998	·2184	...	...	·656	·0868
1·000	·2582*	...	...	·369	·0508
				·106	·0228
0·974	·2299	...	...	·044	·0149
·950	·1948	...	...	·024	·0104
·827	·1245				
·717	·0972				
·368	·0502				
·180	·0329				
·090	·0239				
·015	·0094				

*Condensed water in bulb.

For the second set of experiments the soda-boiled Sakel cotton already referred to was used. The data for the standard curves were obtained from bulbs C and H (Table II); the experiment with bulb K was begun with the cotton in the air-dry condition, while bulbs L and M were used to determine desorption curves from wetness. The cotton in bulb M was dried out over phosphorus pentoxide before soaking in water. The results are given in Table IV and Fig. 4.

Table IV

Adsorption of Water by Soda-boiled Sakel Cotton at 25° C. (Vacuum Method)

Bulb K p/P	Bulb K a			Bulb L p/P	Bulb L a			Bulb M p/P	Bulb M a
0·534	0·0710	...	...	0·966	0·2369	...	.	0·993	0·3165
·675	·0828	...	...	·944	·2108	...	.	·988	·2934
·812	·1067	...	...	·913	·1806	..	..	·971	·2539
·884	·1258	...	...	·833	·1352	...	...	·959	·2220
·935	·1472	...	...	·704	·1011	...	...	·654	·0902
·970	·1685	...	...	·513	·0696	...	..	·306	·0462
·995	·2087	...	..	·293	·0435	...	...	·140	·0288
1·000	·2314*	...	...	·118	·0257				
1·000	·2486*	...	..	·082	·0214				
0·969	·2325								
·936	·1893								
·860	·1453								
·713	·1017								
·290	·0444								

*Condensed water in bulb.

Below a relative vapour pressure of 0·8 all the desorption curves coincide, but above this value the amount of water retained is greater the greater the original excess above the saturation value, so that the upper limit of the equilibrium area is obtained by removing water from thoroughly wet cotton. The data obtained with bulb G (Table III) are of interest in indicating the point at which the highest desorption curve cuts the ordinate corresponding to the saturation pressure. The cotton in this bulb started at a regain of approximately 300%; when the water was removed in stages a series of points was obtained, the pressure remaining constant at the saturation

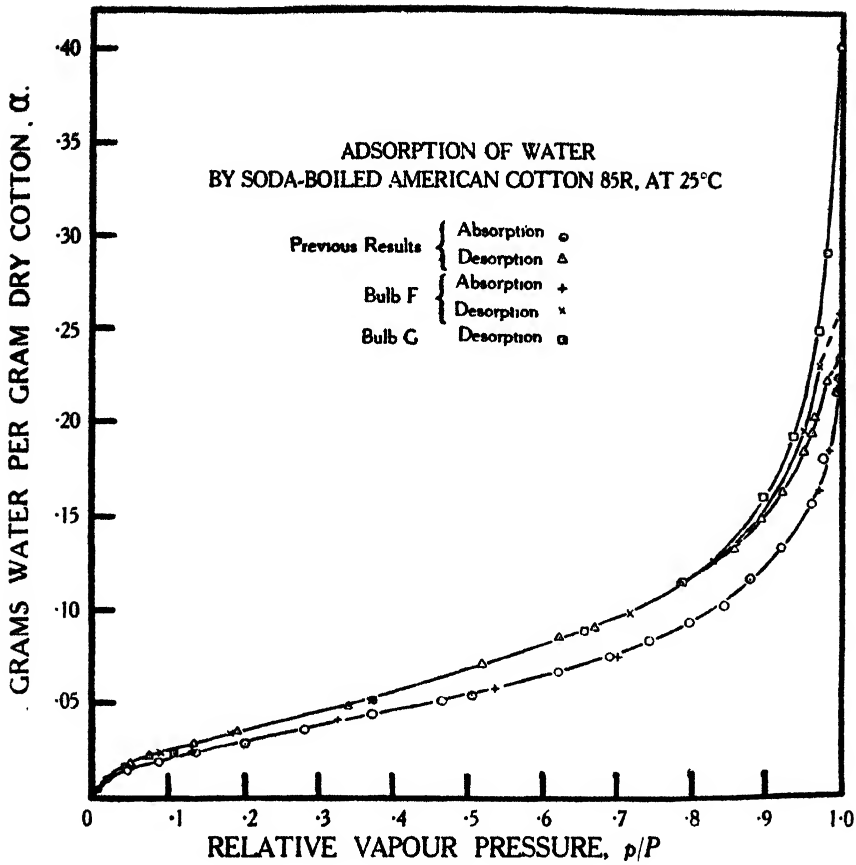
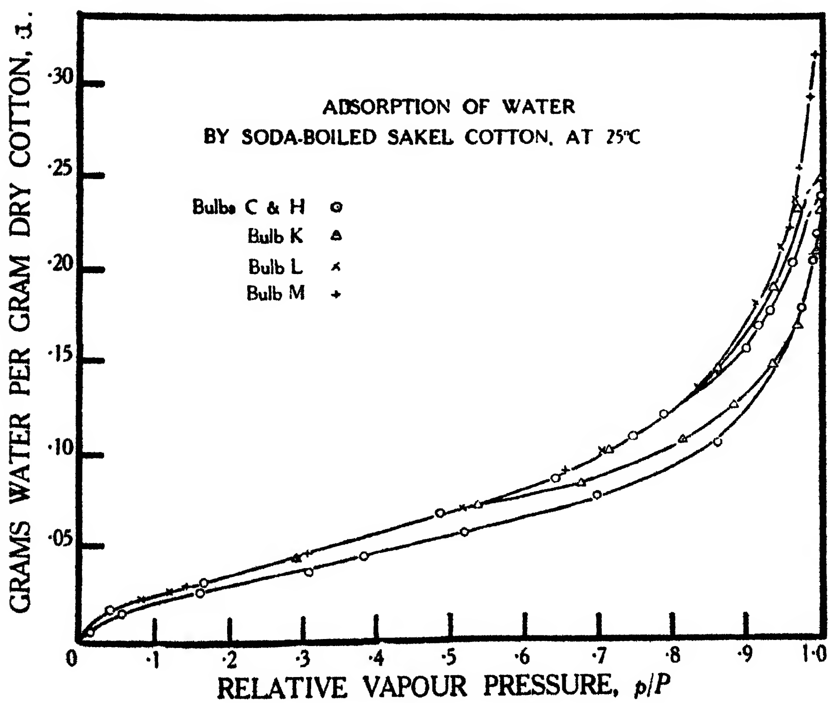

ADSORPTION OF WATER
BY SODA-BOILED AMERICAN COTTON 85R, AT 25°C
Previous Results
Absorption
Desorption
Bulb F
Absorption
Desorption
Bulb G
Desorption
GRAMS WATER PER GRAM DRY COTTON, α.
·40
·35
·30
·25
·20
·15
·10
·05
0
·1
·2
·3
·4
·5
·6
·7
·8
·9
1·0
RELATIVE VAPOUR PRESSURE, p/P

FIG. 3


ADSORPTION OF WATER
BY SODA-BOILED SAKEL COTTON, AT 25°C
Bulbs C & H
Bulb K
Bulb L
Bulb M
GRAMS WATER PER GRAM DRY COTTON, α.
·30
·25
·20
·15
·10
·05
0
·1
·2
·3
·4
·5
·6
·7
·8
·9
1·0
RELATIVE VAPOUR PRESSURE, p/P

value. The last two points of that series are recorded in Table III, and it will be noticed that when α was 0·4027 the relative vapour pressure was still 1·0, though there was no dew noticeable in the bulb. Hitherto in this work the appearance of dew has been an infallible accompaniment of the attainment (and slight over-stepping) of the saturation value, so that it may safely be assumed that this desorption curve cuts the saturation ordinate at a value of α not far removed from 0·4. In this connection it is of interest to recall that Coward and Spencer[1] found that wet cotton retained some 50% of water after centrifuging in a saturated atmosphere, and that some early experiments of one of us indicated that the rate of drying of wet cotton was constant until the regain was reduced to about 40%, when a sharp decrease in the rate was noticeable.

The facts, therefore, seem to be well enough substantiated, but their interpretation is by no means easy. In explanation of the failure of the absorption and desorption curves to meet at the saturation point, it has previously been suggested[9] that if water in excess of the saturation amount is added to cotton in bulk, the spaces between the hairs will become filled, and their subsequent emptying will cause a small reduction of pressure due to the curvature of the water surfaces in them, even while the total amount of water present is still in excess of the saturation value. This still seems to be the most reasonable explanation of this high humidity variability of the desorption curve, but it is not without its difficulties. Thus the variability extends down to $p/P=0{\cdot}8$, a value that corresponds to a capillary radius of 4·7 $\mu\mu$. It may be, of course, that spaces of this magnitude can exist in a tangled mass of cotton hairs of ribbon width approximately 14 μ or 15 μ, but it seems more probable that the lumen or pits in the hair wall would have to be called upon to assist the explanation. Even so there remains the primary difficulty of why such minute pores do not fill during absorption, though it is possible that they are made accessible only as a result of the large swelling consequent on the high absorption at high humidities. To go as far as this, however, is probably to extend the discussion beyond the range of profitable speculation. It should be noted, however, that an explanation on the lines suggested above leads to the conclusion that this variability of the hygroscopicity at high humidities is not so much a property of the material as of its state of aggregation. Some such explanation is evidently desirable, since any other based on changes in the material itself involves the assumption that the cotton adsorbs different amounts of water from liquid water and saturated water vapour—an assumption that cannot be upheld.

Whatever the causes of the effects that have been studied, their immediate consequences are plain enough. When it is desired to condition a number of samples of unknown prehistory at any given humidity and temperature, for example in order to compare their hygroscopicities, it is important to remember that at a given humidity there are many possible values of the moisture regain. Inaccurate results may be obtained if the samples are merely introduced into the test atmosphere without regard to their initial condition. In order that the results may be strictly comparable it is essential that the conditions of the samples should be representable by corresponding points on their equilibrium areas, and the only practical way of ensuring this is to make the measurements in such a way that the representative points of the various samples shall all be on either the standard absorption curve or the standard desorption curve at the test humidity. If a choice

is possible it is better to choose the absorption curve, since by so doing the high humidity variability is avoided, and the determination can be completed in a much shorter time than is possible if atmospheres of high humidity are used. It should be noted from the Figures that transition from one boundary curve to the other is effected not by short direct paths, but by long curves similar in shape to the boundary curves themselves; hence in order to ensure that the condition of the samples may be represented by points on one or other of these curves, before they are conditioned at the test humidity they should be exposed to an atmosphere of humidity as far removed from the test humidity as possible. For example, when it is desired to compare the hygroscopicities of a number of materials in the ordinary atmosphere, they are exposed to an atmosphere of 10% relative humidity for at least six hours before being introduced into the test atmosphere at 70% relative humidity.

Similar considerations apply to the performance of physical tests in which humidity control is important. It is probably safe to say that in all such tests it is the variation of the moisture regain consequent on the humidity change that causes the variation in the measured property, and the controlled humidity is merely a device for securing comparable regains among the samples. From the above discussion it should be evident that this device may not always be effective. It is not suggested that samples for such tests must be treated in the same way as those used for hygroscopicity comparisons, for the variation of the property may be small over the range of possible regain variation at the test humidity. Nevertheless the question ought to be considered, and, if the accuracy of the test warrants it, adequate precautions should be taken in comparisons between samples where large differences of prehistory are known or suspected. In insulation testing, for example, the effect of prehistory is pronounced,[3] and in such work precautions as stringent as those advised for hygroscopicity determinations are probably necessary.

The importance of eliminating hysteresis effects from comparisons has been borne in mind all through this work on the moisture relations of cotton, and the elimination has been accomplished by drying out the cotton at room temperature before determining the curves. It has been recognised that there was a danger of a permanent alteration in the material being produced by this treatment, in view of the fact that drying at high temperatures reduces the adsorptive capacity of cotton, but it seemed preferable to superimpose a small and presumably constant error than to make the comparisons valueless by neglecting the effects of prehistory. The data here presented, however, show that in fact no error has been introduced—drying out at room temperature causes no permanent alteration of the material. Thus all save one of the intermediate absorption curves of Figs. 1, 2, and 4, determined with materials that had never been dried out, eventually run into the standard absorption curves from dryness. The one exception is the upper intermediate curve of Fig. 2, which is throughout higher than the standard curve. No great importance need be attached to this curve, however, for the other curve for the same material (Fig. 4), which starts from approximately the same point, runs into the standard curve at about 95% relative humidity. The anomalous curve is also peculiar in another way; the divergence of the points from the smooth curve drawn among them is much greater than is usual in this work. Again, it is evident that drying out at room temperature has no effect on subsequent desorption curves; the desorption curves given

by bulbs L and M are identical (Fig. 4), though the cotton in M only was dried before the determination.

In a previous paper[7] it was mentioned that cotton taken direct from the boll or from the washing-off after kier-boiling or mercerising had initially a very high adsorptive capacity. At the time the paper was written the experiments were still in progress, and though the effect was quite well substantiated qualitatively no data could be presented, and diagrammatic curves only could be reproduced. The experiments have now been concluded and the results are given below. The desiccator method was used throughout.

Two varieties of raw cotton were examined, Webber and Acala. Careful watch was kept on some bolls on plants growing in the greenhouse, and on the first signs of their bursting the cotton was removed to weighing bottles, and the desorption curves determined in the usual way. The cotton was then dried out at room temperature and the standard absorption and desorption curves were determined. The results are given in Table V and the curves for the Webber cotton are reproduced in Fig. 5. The curves for the Acala cotton are little different from those for the Webber. as will be evident from Table V.

Table V

The Adsorption of Water by Raw Webber and Acala Cottons, and by Soda-boiled and Mercerised Sakel Cotton at 20° C. (Desiccator Method)

	a			*b*			
p/P	Raw Cottons		*p/P*	Soda-boiled and Mercerised Sakel Cotton			
	Webber	Acala		Sample (a)	Sample (b)	Sample (c)	Sample (d)
0·878	0·222	0·221	0·906	0·194	0·182	0·281	0·276
·766	·145	·146	·777	·128	·123	·182	·181
·642	·1058	·1066	·646	·0949	·0928	·136	·136
·419	·0640	·0645	·413	·0577	·0572	·0854	·0846
			All samples dried out.				
·403	·0556	·0558	·405	·0486	·0481	·0688	·0672
·608	·0798	·0791	·626	·0721	·0716	·1026	·1004
·749	·1034	·1037	·767	·0914	·0909	·130	·127
·896	·152	·152	·857	·113	·112	·161	·157
·948	·193	·194					
	Exposed over water			Squeezed out in water			
·949	·216	·219	·904	·168	·166	·235	·232
·904	·181	·185	·758	·113	·112	·158	·156
·788	·129	·132	·603	·0844	·0841	·120	·119
·589	·0904	·0910	·414	·0574	·0575	·0838	·0833
·414	·0637	·0647					

The soda-boiled and mercerised cottons were examined in the same way, except that after the determination of the standard absorption curve the cottons were steeped in water and squeezed out, in order that the high humidity variability might be eliminated from the comparison of the primary and standard desorption curves. The material used was the soda-boiled Sakel cotton, and the samples were as follows—

Sample (*a*)—Taken wet from the wash-off.

Sample (*b*)—Allowed to dry in the air for about 24 hours, then wetted out.

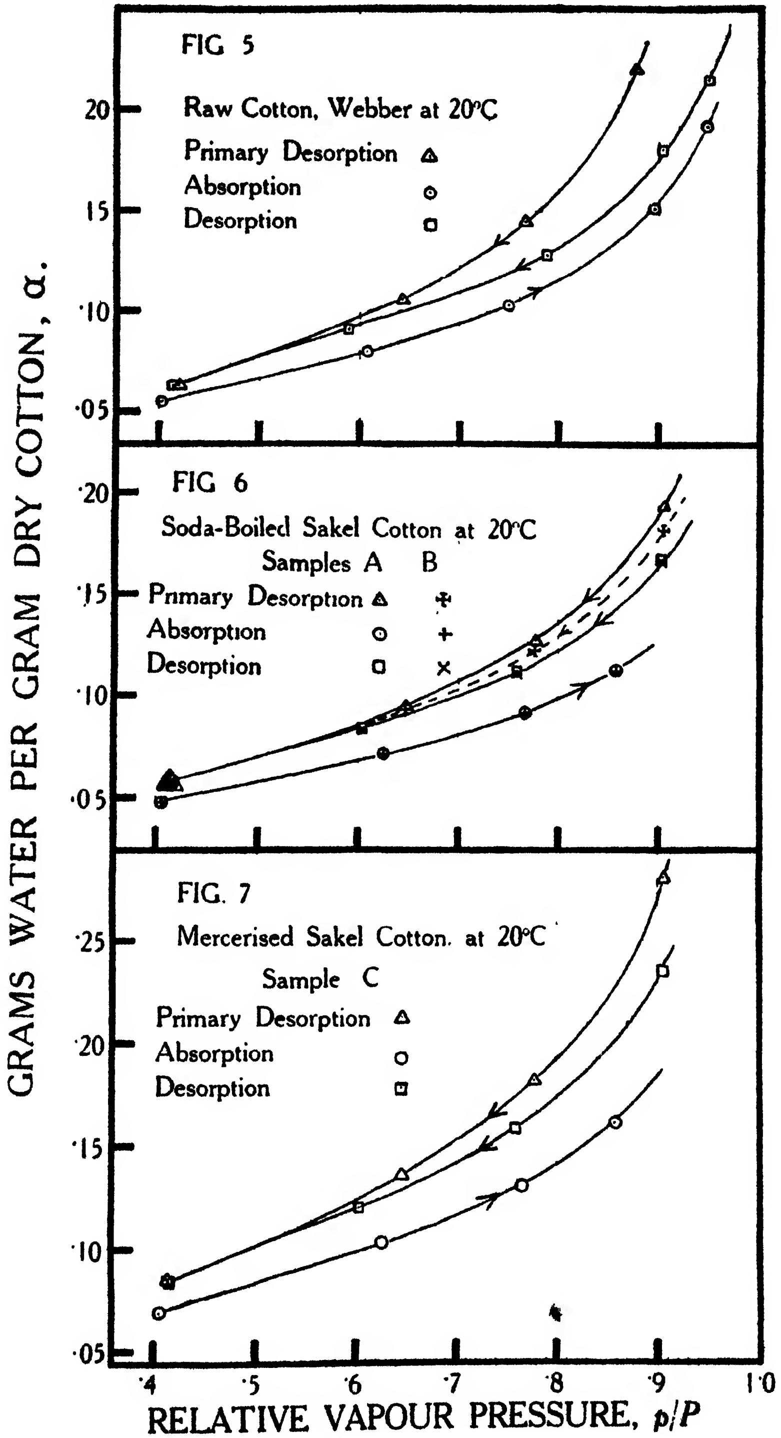
Sample (*c*)—Taken wet from the wash-off, mercerised without tension in 25% sodium hydroxide solution, washed, and started wet.

Sample (*d*)—Allowed to dry in the air for about 24 hours, mercerised without tension in 25% sodium hydroxide solution, washed, and started wet.

The results for these materials are given in Table V, and Figs. 6 and 7.

The curves in these figures are all similar in form and show that cotton from the boll, or immediately after kier-boiling or mercerising, has the power of adsorbing very large amounts of water. The primary desorption

curve, however, runs into the standard desorption curve somewhere about 50% relative humidity, so that if the material is air-dried to this extent, subsequent changes are effected on the normal equilibrium area. Sample (*b*)



was not dried as far as this before it was rewetted, and its primary desorption curve lies below that of sample (*a*) but above the standard desorption curve common to both. It is probable, therefore, that the area between the two desorption curves may also be regarded as an equilibrium area, but of a different kind from that between the standard absorption and desorption curves. The impairment of the adsorptive capacity brought about by drying probably occurs continuously down the primary desorption curve, so that after drying down to a given point on it a certain part of the area above that point is no longer capable of representing the condition of the material, until when the standard desorption curve is reached at about 50% relative humidity the whole of the upper area is excluded.

In order to avoid confusion the results obtained with sample (*d*) are not shown on Fig. 7; it appears from Table V, however, that even the large swelling in mercerisation may not be sufficient to counterbalance the changes brought about in the first air drying of the soda-boiled cotton, for the material mercerised wet adsorbs more water than that mercerised after air drying. The difference is small, however, and is not likely to have any practical significance.

The enhanced hygroscopicity of cotton immediately after kier-boiling or mercerising is probably accompanied by a correspondingly high degree of swelling, and it is interesting to inquire whether this condition could be utilised to advantage in subsequent processing. Knecht[2] has shown that mercerised yarn dyed before drying absorbs more dye from a given bath than the same material dyed after air drying. This effect has been followed qualitatively by dyeing with direct, sulphur, and vat dyes, kier-boiled and mercerised cloth dried to various stages between wetness and dryness. The various partially dried samples were not noticeably different, but there was a pronounced difference between them and the samples dyed wet (carrying about their own weights of water). The latter were darker in shade, and the colours, in the opinion of trade referees, were "brighter" and more "alive." The advantages of dyeing without previous drying would therefore appear to be considerable, and similar advantages might be expected from the use of such methods in any wet process in which a high degree of swelling of the cotton is desirable. Difficulties, however, would probably be encountered in the practical application of the methods, so that the view here advanced must be regarded merely as an indication of one direction in which improvement of such processes might be sought.

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THE JOURNAL OF THE
TEXTILE INSTITUTE
TRANSACTIONS

33—THE FOUNDATIONS OF YARN-STRENGTH AND YARN-EXTENSION

PART III—THE CLINGING POWER OF COTTON

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SUMMARY

The present paper describes tests to determine the clinging power of certain standard Indian cottons which had given spinning test results that were somewhat unexpected in view of their other fibre-properties. The method used was a modification of Adderley's, and consisted of pulling a group of 10 fibres of a cotton between pads made from parallelised fibres of the same cotton and subjected to a known pressure; the pads were ⅜ in. long; the force was applied and measured by means of an O'Neill's fibre-strength tester. The clinging power is taken to be the force required to pull the 10 fibres through the pads under a known pressure. The various sources of errors are discussed, and the conclusion reached that these are not serious.

Some preliminary experiments were made to determine the effect of differences of pressure between the friction pads, and finally a load was chosen to produce such a pressure as would not differ greatly from that experienced by the fibres of a yarn on the point of breaking under tension. This load was used in all the subsequent experiments. The following are the conclusions reached in the experiments on various standard Indian cottons using standard pressure between the friction pads.

(1) The clinging power depends upon the pressure acting on the fibres, increasing as the pressure increases, though the relative magnitude of the increase is not so rapid as that of the pressure itself.

(2) The cottons which are suitable only for comparatively low counts tend to have a high individual clinging power; it is possible that this property is partly responsible for the irregularity of the yarns spun from them and for the impossibility of spinning them economically to a high count.

(3) There is comparatively high correlation between the highest standard warp counts and the clinging power of the whole fibre per unit fibre-weight per inch, showing that there is a tendency for those cottons which have high clinging power in relation to their length and fineness to be spinnable to a comparatively high standard count.

(4) The clinging power per unit fibre surface shows less variation than the clinging power or the clinging power of the whole fibre per unit fibre-weight per inch; and it appears that even if the clinging power per unit fibre surface is not the same for different cottons, it is at any rate a property which is unrelated to the highest warp counts to which a cotton can be spun.

(5) The shorter and coarser cottons tend to have higher individual clinging power, but in the yarn the greater number of the finer and longer fibres present offsets the greater individual clinging power of the coarser fibres, so that the finer fibres actually have a much higher total clinging power in a yarn of a given count.

I. INTRODUCTION

In Part I of the present series of papers[1a] a list was given of certain fibre-characters which appeared to be of greatest importance in contributing to the strength of yarn. The fifth property in the list was "clinging power." In discussions of the strength of cotton yarn it has been customary to assign an important rôle to the surface friction, or, more correctly, the clinging power of the fibres. Thus Bowman[2] put surface friction fifth in the list of

important fibre-properties; and other writers have equally referred to the importance of this property. Balls[3a] in his latest book also comes to the conclusion that clinging power is one of four all-important properties of the cotton fibre which determine the strength of the yarn which can be made from it. As was pointed out, however, in Part II[1b], the question of yarn rupture by fibre-slippage or by fibre fracture must be considered in relation to the twist. Adderley[4a] in his paper on "The Clinging Power of Single Cotton Hairs" states that "when soft spun yarn is broken, the majority of the hairs are not fractured, but merely slip one over the over, and although this slip diminishes in more tightly twisted yarns, it must still play some part, even in ostensible 'snap' breaks." He seeks to trace the connection between the clinging power of cotton hairs and the number of convolutions present therein, and concludes that "the clinging power of cotton hairs depends upon the convolutions, and presumably this power is a factor important in the spinning value of the cotton and the strength of the yarn spun from it, especially in soft twisted yarns." In yarns of very low twist it is indeed possible that fibre-slippage plays a prominent part, though from experiments which will be described in Part IV, dealing with the influence of yarn-twist on the proportions of fibre-fracture and fibre-slippage in yarn-breakage, it will be clear that even in what are known commercially as soft-twisted yarns the yarn-strength is determined chiefly by the extent of fibre-fracture.

Perhaps the best test of the importance of clinging power is the determination of how far it contributes to the spinning value of a cotton. One of the chief aims at the Technological Laboratory is the accumulation of data for the purpose of predicting the spinning value of a cotton from a knowledge of its fibre-properties. If then clinging power is of importance in this connection, it must evidently be included in the routine examination of a sample undertaken with this end in view. In "Technological Reports on Standard Indian Cottons, 1927[5]" attention was drawn to certain anomalies in the spinning test results which could not apparently be explained in terms of fibre-length, fibre-weight, and fibre-strength; it was suggested that these anomalies could be explained by differences in the numbers of convolutions of the different fibres leading to effective differences in surface friction. Experiments were accordingly begun in January 1928 with a view to testing this explanation, but the results obtained soon showed that it must be discarded, and the explanation was accordingly dropped in the next edition of "Technological Reports" and other possibilities were explored. However, the determination of clinging power was continued until a complete series of results was obtained for those cottons which have given unexpected results, and the present paper describes the results obtained.

II. EXPERIMENTAL METHODS AND MATERIAL

The only published description of experiments for the direct determination of clinging power is that of Adderley[4a], whose method consisted of determining the force necessary to pull a single fibre of a given cotton between two pads pressed together under a known load and covered with fibres of the same variety as that under test; the arrangement of the fibres on the pad was such that their longitudinal direction coincided with the direction in which the single fibre was pulled. Adderley found that the same fibre pulled between the same pads a number of times successively gave very different values for the force required, and he therefore took the average of a number of such values as a measure of the clinging power of the fibre in question.

Adderley's method is of course empirical and can hardly be regarded as satisfactory. The difficulty is to find a better method. Balls[3b], in discussing the problem, states that he "had hopes that Adderley's method would have been susceptible of development, but critical study of it has so far been disappointing in this respect." Balls himself eventually made measurements of clinging power by determining the breaking strengths of rovings of different cottons made in the same counts. A few tentative experiments were made at the Technological Laboratory by preparing a roving of definite length from a given weight of cotton by means of the draw-box of a Balls Sorter; but this method was not persevered with as it seemed too unpromising. Balls[3c] also mentions the possibility of making experiments after this manner. In the end it appeared that the simplest method of carrying out these experiments was by some modification of Adderley's method; some preliminary tests on single fibres, as in the original method, gave such widely different results both for a single fibre tested repeatedly and for the means of such results for several single fibres, that the testing of single fibres was discarded, and instead, groups of 10 fibres were mounted together and drawn through the pads simultaneously. With this arrangement it was found that repetitions of the operation gave much more consistent results. The method had the advantage that a greater force was necessary to pull 10 fibres through the pads, and this force could therefore be measured more accurately.

For the tests on any given cotton a carefully selected sample was first made into a sliver so as to ensure proper mixing of the fibres. Two pads were then prepared by extracting fibres from the sliver, placing them over the front (A, Fig. 1) of a small glass slip and fixing their ends at the back (B, Fig. 1) with rubber solution; the parts of the fibres on the front of the glass slip were $\frac{3}{8}$ in. long in all experiments. The apparatus used is shown in Fig. 2, and was made according to Adderley's description[4b], a light triangular framework AED is pivoted at P, it carries a weight W at E, and one of the friction pads at A; the other pad is carried on a block X arranged so that the surfaces of the pads are vertically below P. The pressure of one pad on the other caused by the weight of the framework was found to be equivalent to that of two grams at E; the values of W referred to hereafter are the corrected weights, making this due allowance for the weight of the framework. Some preliminary experiments were made with various values of W, *viz.* 22, 52, and 72 grams respectively; in the final experiments W was invariably 72 grams.

As previously mentioned, in each of the present experiments, a group of 10 fibres was pulled between the parallel fibres on the friction pads. The ends of the 10 fibres were mounted with wax on an eyelet C (Figs. 1 and 2), the fibres being placed as nearly parallel as possible. The eyelet C is for the attachment of a hook fixed in the upper end of the float G. of an O'Neill's apparatus used in conjunction with the other parts already described. All the fibres attached to the eyelet were well over $\frac{3}{8}$ in. in length, in order to ensure that some part of each fibre should protrude above the pads bejore the eyelet C was pulled down by the float. In conducting an experiment, the liquid in the tube H was drained off until the fibres attached to the eyelet showed that they were just being subjected to tension, and from this point onwards the liquid, as it was drained off, was collected in a measuring cylinder. The gradual withdrawal of the liquid exerts a gradually increasing pull upon the eyelet and the fibres attached to it, until the fibres slip through the pads. It

is this maximum frictional resistance which is taken as the clinging power of the group of 10 fibres, the fibres being drawn between pads ⅜ in. long covered with the same cotton and caused to press against each other by a known weight at E (normally 70 grams). When the fibres slip through the pads the flow of liquid is stopped, and the volume of the run-off liquid is measured; a preliminary calibration of the apparatus enables the clinging power to be calculated from the volume of the liquid collected in the measuring cylinder; the liquid used for this purpose is a solution of calcium chloride having approximately the same vapour pressure as that of the aqueous vapour in the surrounding air at the time of the experiment.

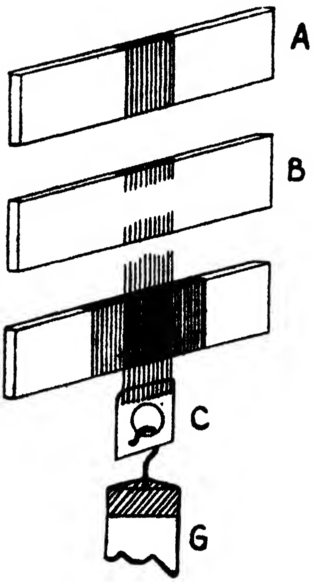

FIG. 1

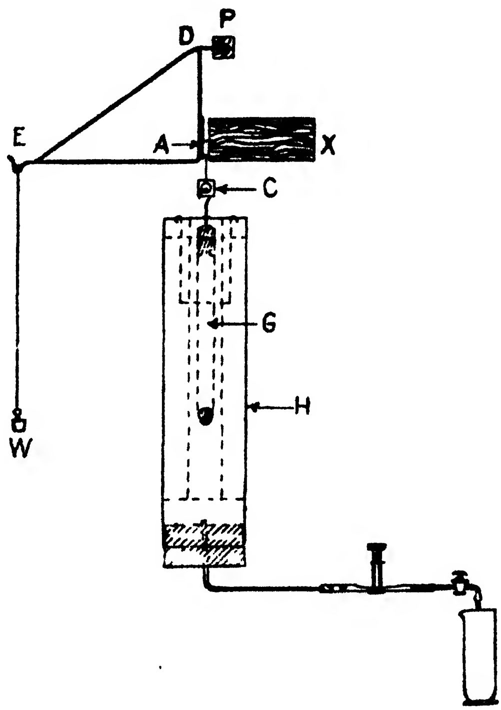

FIG. 2

Sources of Error.

Sources of Error. (1) In using the O'Neill apparatus there is some uncertainty as to the zero position, i.e. the exact position at which the fibres are first subject to load as the liquid is withdrawn from the tube H; a close watch is kept to note this position, and the error arising must be quite small.

(2) It is not possible to stop the flow of liquid exactly at the moment when the fibres begin to slip; the effect of this source of error is made small by employing a low rate of flow.

(3) Owing to the changing head of liquid in tube H, the liquid does not flow out at a constant rate; however, even for the maximum load the change in head was not more than 25 per cent. so that the effect of the change in the rate of loading is not likely to have been serious.

(4) The 10 fibres in a group may not be strictly parallel and sometimes may even cross each other, owing to the difficulty of adjusting the fibres between the pads. However, the effect of the tension in the fibres during the test tends to straighten them and so to diminish this error.

(5) The experiments on different varieties of cotton were made at somewhat different temperatures and relative humidities, but no correction could be applied as the effects of temperature and humidity on clinging power are unknown. At the same time it may be remarked that in no case was the temperature and seldom was the relative humidity appreciably different from what is satisfactory for the spinning of cotton.

(6) By far the most important source of error, however, is derived from the structure of the pads. It is impossible to arrange the fibres on the pads in a perfectly uniform and parallel manner; hence the pressure on a fibre depends to a certain extent upon its position between the pads. The error is partially eliminated by Adderley's method of taking repeated readings with the same group of fibres.

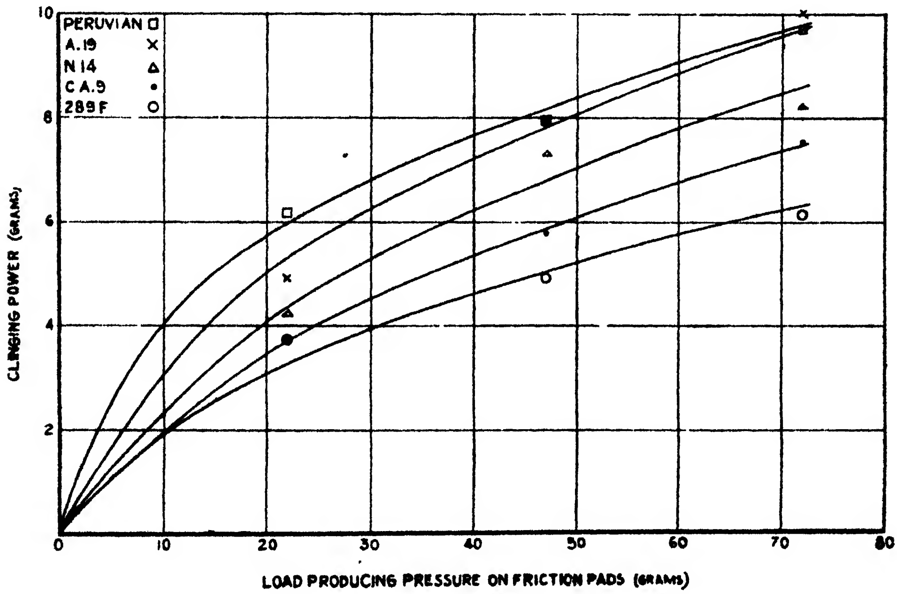

Fig. 3

III. DISCUSSION OF RESULTS

(1) The Effect of Differences in Pressure between the Friction Pads.

Reference has already been made to the preliminary tests in which single fibres only were drawn between the pads.

Another point which required investigation was the size of the effective weight W to be employed in producing pressure on the pads. Ideally, W should be large enough to cause a pressure comparable with that sustained by the fibres in a yarn subjected to a breaking test. But the difficulty arises that as the pressure is increased the average load borne by the fibres may be more than enough to break some of them, owing to the great variability of fibre-strength. In order to avoid this difficulty, the pull necessary to cause the fibres to slip through the pads should not exceed about a gram per fibre, or from 15 to 30 per cent. of the mean strength of the fibres. It may

be noted that a great advantage accrues from having the friction pads only $\frac{3}{8}$ in. long, because the pull necessary to overcome the frictional resistance on a $\frac{3}{8}$ in. length is obviously much less than would be required for the whole length of the fibre, and it therefore permits the employment of much greater pressure on the friction pads, which may in fact be increased until the frictional resistance of the $\frac{3}{8}$ in. length itself is only just below the breaking strength of the fibre. In some preliminary tests, breakage of one or more of the group of 10 fibres was found to occur frequently when the weight applied at E amounted to 100 grams, and occasionally with a weight of 70 grams. In order to obtain some further idea of the effect of differences in the effective weight, W, some experiments were then made on five different cottons, and the clinging power of each of these was measured with W equal to 22, 52, and 72 grams respectively. The results are given in Table I, and are shown graphically in Fig. 3.

Table I

The Effect of Differences of Pressure Between the Friction Pads.

Cotton	Season	Load producing pressure on pads (grams)	Clinging Power (grams)
Peruvian	—	22	6·18
		52	7·98
		72	9·73
P. A. 289F	1926-27	22	3·76
	,,	52	4·95
	,,	72	6·14
Aligarh A. 19	1926-27	22	4·97
	,,	52	7·93
	,,	72	10·05
C. A. 9	1926-27	22	3·74
	,,	52	5·82
	,,	72	7·54
Nandyal 14	1926-27	22	4·27
	,,	52	7·31
	,,	72	8·23

If the conditions were comparable with those of plane friction it would be expected that the clinging power would be directly proportional to the pressure between the pads, and therefore to the effective weight W; actually, however, it was found not to be so, for the clinging power increased less rapidly than the effective load W. The explanation of this result is probably that a part of the pull on the fibres is needed to overcome the frictional resistance due to the fibre-crimp; but as the pressure is increased and a greater pull is needed, the greater tension to which the fibres are subjected straightens them out, and so removes the contribution of the crimp to the frictional resistance.

In view of the form of the curve connecting the effective weight with the clinging power, the question arises as to how far it is legitimate to apply these results in the case of yarn-breakage. As will be seen from the figures in Table I, even with the 72-gram load the clinging power per $\frac{3}{8}$ in. length

rarely amounts to as much as 10 grams for 10 fibres, or one gram per fibre. For the whole length of the fibre (say one in.) the clinging power would be approximately 2·7 grams per fibre. We may compare this force with the tension sustained per fibre by a yarn at the breaking point. For example, in a 20's yarn of some cottons (e.g. Gadag 1 and Cambodia) the average number of fibres in the cross-section is about 165; taking the average breaking strength of the yarn spun with 3·75 twist-constant as about 10 oz., we find the average load per fibre to be 1·7 gram, or about two-thirds the clinging power. However, at the breaking place the number of fibres will normally be decidedly less than the average of the whole length of yarn, and so we reach the conclusion that with an effective load of 72 grams the pressure exerted by the friction pads is in the neighbourhood of that experienced by the fibres of a yarn subjected to a breaking test. We are therefore justified in adopting an effective load W, of 72 grams, as the standard load in these clinging power experiments.

(2) Experiments on Various Standard Indian Cottons with Standard Pressure between the Friction Pads.

Adderley's experiments were carried out on five different cottons, but the total number of fibres tested by him amounted to only 89. He does not give the actual average load required to pull a single fibre through the friction pads, nor does he give the value of the effective load producing the pressure between the pads; the results for the load required to pull a single fibre through the pads are given only in terms of the "water withdrawn to cause slip." For the five different types of cotton tested the average values obtained were as follows—

Sea Island (AN 2-8-18)	21·0
Sea Island (V 135)	24·9
Southern Cross Upland	25·3
Sennaar Tree	24·4
Trinidad Native 2	34·2

In view of the fact that Adderley states[4b] that "the pads are pressed together with a constant force which can be adjusted to suit the needs of the experiment," it is doubtful whether these average figures may be taken to measure the relative clinging powers of the different cottons; if they do so, it is somewhat surprising that the mean values for the second, third, and fourth cottons differ so little, in spite of the extremely different natures of the cottons and of the great differences in their other fibre-properties; and while the recording of the actual load required to cause slip of the single fibre, and of the effective load causing pressure on the pads, and other details, may have been unnecessary for Adderley's immediate purpose, which was to trace the relation between clinging power and the number of convolutions in a fibre, yet the absence of these details makes it impossible to compare his results with those obtained in the present series of experiments.

As previously explained, the main purpose of the present experiments was the elucidation of anomalies encountered in the spinning tests on the standard Indian cottons; 13 of these cottons were tested for clinging power, and as seven of them had given diverse results in different seasons, samples of their different seasons' growth were tested, bringing the total number of samples tested to 45. In each case the clinging power was determined for 25 groups of 10 fibres, and the mean thence determined for a single group of 10 fibres. As in Adderley's method, each group was normally tested more

than once (actually twice or thrice), and the mean of the readings taken as the clinging power of the particular group. As an example of the range of values obtained in the repeated testing of the single groups, and in the testing of 25 separate groups, the following table is given showing the individual results obtained for Gadag 1, 1927-28.

Table II

Results of Individual Tests of Clinging Power for Gadag 1, 1927-28.

Group No.	No. of Repeat Test			Mean of Repeat Tests
	1	2	3	
1	6·3	4·3	6·3	5·6
2	4·7	8·4	6·2	6·4
3	5·9	7·1	4·8	5·9
4	8·2	—	—	8·2
5	7·1	7·1	5·7	6·6
6	5·9	4·9	4·3	5·0
7	6·9	—	—	6·9
8	5·2	5·9	6·3	5·8
9	4·2	4·8	4·6	4·5
10	8·4	5·8	4·0	6·1
11	9·5	7·0	—	8·2
12	7·9	12·9	—	10·4
13	9·1	5·8	5·5	6·8
14	7·5	6·6	7·5	7·2
15	7·6	4·9	7·0	6·5
16	6·3	—	—	6·3
17	8·7	7·2	—	7·9
18	7·5	4·5	—	6·0
19	7·9	7·1	6·7	7·2
20	8·6	6·3	—	7·4
21	10·2	—	—	10·2
22	7·0	—	—	7·0
23	6·7	7·6	8·7	7·7
24	5·9	4·5	4·7	5·0
25	6·6	5·9	5·5	6·0
			Grand mean	6·83

Now the clinging power of cotton may assume importance in two directions; first, it may influence the manner of formation of the yarn in the various processes of spinning—particularly in drafting; and secondly, it may be of importance in the strength of the spun yarn. So far as the second point is concerned, it is clear that we have to take into consideration not only the clinging power as determined by the method herein described, but also the fibre length and fibre-weight per in. The clinging power is determined on a $\frac{3}{8}$ in. length of fibre; if the friction pads were large enough to take the whole length of the fibre, and the pressure per unit area between the pads remained the same, then other things being equal, the clinging power of a fibre would be proportional to its length; and though other things are not equal, this relationship can no doubt be regarded as true to a first approximation. Again, the frictional resistance of a yarn to tension depends on the number of fibres in the cross-section, and as the clinging power is expressed as *per fibre* (or group of 10 fibres), it follows that in order to obtain the frictional resistance of the yarn to breakage we must multiply the clinging power per fibre by the number of fibres in the cross-section, this number being inversely proportional to the fibre-weight per inch. Hence the true

Table III. THE CLINGING POWER OF SOME STANDARD INDIAN COTTONS

Serial No.	Cotton	Season	Highest standard counts	Clinging power (c): Mean (oz.)	Clinging power (c): Probable error single observation	Clinging power (c): Temperature (°F.)	Clinging power (c): Relative humidity %	Length (inch) (l)	Clinging power per whole fibre $\left(c \times \frac{8}{3} l\right)$	Fibre-weight per inch (w)	Clinging power per unit fibre surface $\left(\frac{c}{\sqrt{w}}\right)$	Clinging power per whole fibre per unit fibre-weight per inch $\left(c \times \frac{8}{3} l \times \frac{1}{w}\right)$
1	Gadag 1	1923–24	36	0·269	15	83	82	0·87	0·628	0·174	0·64	0·360
2	"	1924–25	20	0·249	12	89	64	0·80	0·534	0·154	0·63	0·347
3	"	1925–26	30	0·255	15	87	72	0·82	0·558	0·150	0·66	0·371
4	"	1926–27	38	0·280	14	86	74	0·81	0·605	0·179	0·66	0·339
5	" (A)	1927–28	38	0·241	13	84	75	0·86	0·553	0·167	0·59	0·331
6	" (B)	1927–28	24	0·256	14	86	73	0·81	0·553	0·182	0·60	0·304
7	" (C)	1927–28	32	0·258	11	84	69	0·83	0·571	0·164	0·64	0·347
8	"	1928–29	26	0·306	9	84	70	0·82	0·673	0·162	0·76	0·416
9	Wagad 4	1925–26	14	0·393	10	86	66	0·80	0·838	0·253	0·78	0·331
10	"	1926–27	16	0·350	13	84	46	0·85	0·793	0·257	0·69	0·309
11	"	1927–28	18	0·310	11	79	55	0·79	0·657	0·181	0·73	0·363
12	"	1928–29	16	0·335	10	85	66	0·84	0·755	0·216	0·72	0·349
13	Wagad 8	1925–26	12	0·419	16	85	69	0·78	0·872	0·258	0·82	0·339
14	"	1926–27	14	0·339	11	84	64	0·80	0·728	0·264	0·66	0·275
15	"	1927–28	15	0·284	20	79	70	0·77	0·583	0·189	0·65	0·309
16	"	1928–29	15	0·403	9	82	68	0·80	0·865	0·239	0·82	0·360
17	285 F	1923–24	34	0·260	9	84	73	0·93	0·645	0·123	0·74	0·523
18	"	1924–25	34	0·270	11	84	74	0·92	0·666	0·152	0·69	0·437
19	"	1925–26	28	0·296	10	84	77	0·95	0·750	0·155	0·75	0·483
20	"	1926–27	34	0·266	13	82	77	0·82	0·582	0·104	0·82	0·560
21	"	1927–28	34	0·270	13	83	70	0·89	0·641	0·133	0·74	0·483
22	"	1928–29	34	0·276	11	84	73	0·88	0·648	0·125	0·78	0·520
23	289 F.	1926–27	38	0·217	8	86	65	0·97	0·561	0·098	0·69	0·571
24	A. 19	1926–27	7	0·355	14	86	67	0·66	0·625	0·301	0·65	0·208
25	C. A. 9	1924–25	28	0·300	13	84	43	0·89	0·716	0·163	0·74	0·440
26	"	1925–26	28	0·314	9	80	47	0·87	0·728	0·147	0·82	0·496
27	"	1926–27	34	0·266	11	81	53	0·87	0·621	0·182	0·62	0·341
28	"	1927–28	30	0·290	9	81	45	0·86	0·669	0·176	0·69	0·381
29	"	1928–29	40	0·279	11	84	51	0·89	0·662	0·166	0·68	0·400
30	Umri Bani	1927–28	24	0·271	10	88	63	0·81	0·589	0·192	0·62	0·307
31	Co. 1	1923–24	32	0·234	12	84	78	0·92	0·574	0·171	0·57	0·336
32	"	1924–25	30	0·284	12	83	84	0·87	0·659	0·147	0·74	0·448
33	"	1925–26	32	0·238	11	85	75	0·93	0·590	0·156	0·60	0·379
34	"	1926–27	38	0·309	10	88	72	0·92	0·762	0·155	0·78	0·491
35	"	1927–28	34	0·301	9	88	67	0·93	0·750	0·164	0·74	0·459
36	"	1928–29	32	0·291	9	86	71	0·93	0·722	0·170	0·71	0·424
37	N. 14	1926–27	34	0·290	12	83	63	0·93	0·723	0·191	0·66	0·379
38	H. 25	1923–24	24	0·274	16	78	46	0·90	0·661	0·210	0·60	0·315
39	"	1924–25	28	0·313	12	85	66	0·86	0·722	0·172	0·75	0·419
40	"	1925–26	26	0·308	10	86	46	0·85	0·698	0·178	0·73	0·392
41	"	1926–27	26	0·277	14	79	57	0·76	0·561	0·177	0·66	0·317
42	"	1927–28	26	0·309	11	83	52	0·87	0·721	0·205	0·68	0·352
43	"	1928–29	30	0·316	12	82	42	0·90	0·758	0·188	0·73	0·403
44	Karunganni	1926–27	24	0·260	11	85	49	0·85	0·589	0·192	0·59	0·307
45	Memphis	1925–26	38	0·289	11	82	61	0·95	0·736	0·181	0·68	0·408

A, B, and C represent three different samples of Gadag 1 grown under different conditions in 1927–8.

measure of relative clinging power in comparing yarn strengths is the clinging power of the whole length of the fibre, expressed as per unit fibre-weight per inch. In Table III, therefore, showing a summary of the results for clinging power are also included the values obtained for the fibre-length (l), the fibre-weight per inch (w), the clinging power per whole fibre ($c \times 8l/3$), and the clinging power per whole fibre divided by the fibre-weight per inch ($c \times 8l/3 \times 1/w$). The values are also included of the clinging power divided by the square root of the fibre-weight per inch ($c/\sqrt{w}$); this may be taken as a very approximate measure of the clinging power *per unit surface area* of the fibre.

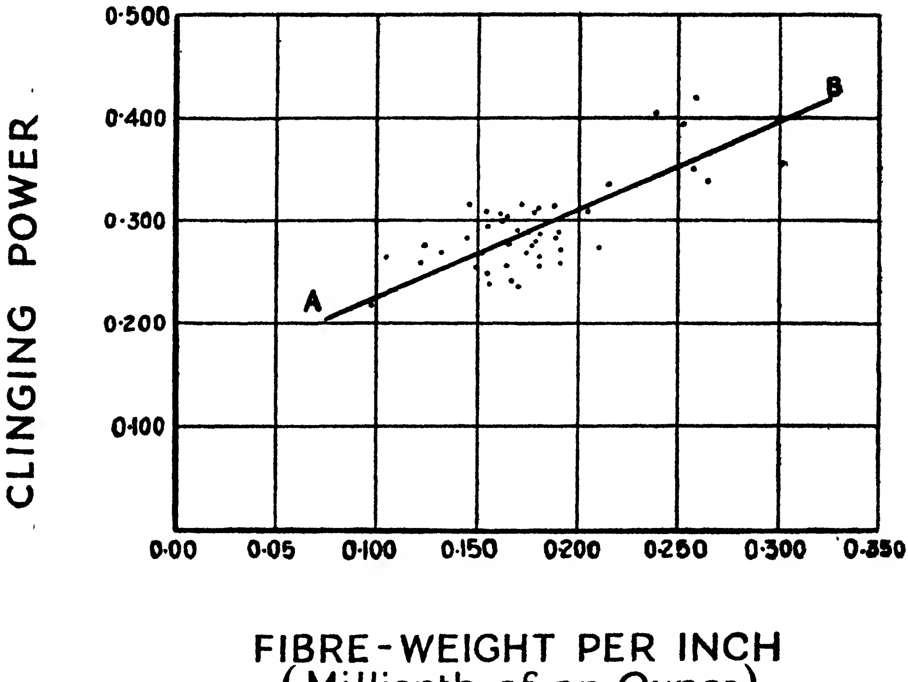

FIG. 4

This line has been calculated by the method of least squares. The fibre weight values have been given the weight "3," while the clinging power ones have unit weight

From this table it is clear that generally it is the low count cottons which have high clinging power, and the correlation coefficient between the two quantities is $-0{\cdot}67$. This value is comparatively high, and certainly significant in the statistical sense. So far as yarn strength is concerned this result would appear paradoxical but for the fact, already pointed out, that in yarn strength we must consider not the clinging power itself but the clinging power of the whole fibre per unit fibre-weight per in. At the same time, the comparatively high negative value of the correlation between the clinging power itself and the count spinnable is possibly very significant so far as concerns the behaviour of the cotton in the drafting processes of spinning. Under these conditions high clinging power is undesirable, and it is conceivable that the high clinging power of the low count cottons is at least partly responsible for the irregularity of the yarns spun from them, and for the impossibility of spinning them economically to a high count.

Table IV shows the mean value, standard deviation, and coefficient of variation, for the following properties of all the cottons—counts, length, fibre-weight per inch, clinging power, and certain derived quantities. The magnitude of the coefficient of variation is an indication of the "spread" of the values; thus the "spread" is greatest for the highest standard warp counts, large for the fibre-weight per inch, and least for the fibre-length. The "spread" is connected with the range of values, which is from 7's to 40's for counts, from 0·098 to 0·301 ($\times 10^{-6}$ oz.) for fibre-weight per inch, and from 0·66 to 0·97 in. for fibre-length. It is interesting to note that the clinging power and the clinging power per whole fibre each have a moderate spread, and a range from 0·217 to 0·419 and 0·534 to 0·872 respectively; but the clinging power of the whole fibre per unit fibre-weight per inch shows greater variation, its range being from 0·208 to 0·571. The clinging power divided by the square root of the fibre-weight per inch shows comparatively little variation, its range being from 0.57 to 0·82.

Table IV

Mean Values and Variations of Properties of Some Standard Indian Cottons

Property	Mean	Standard Deviation	Coefficient of Variation (%)
Clinging power (c) (oz.)	0 293	0·042	14
Highest standard counts (x)	27·7	8·2	30
Length (l) (inch)	0·86	0·06	7
Clinging power per whole fibre $\left(c \cdot \times \frac{8}{3} l\right)$ ...	0·669	0·085	13
Fibre-weight per inch (w) (10^{-6} oz.)	0·179	0·041	23
Clinging power per whole fibre per unit fibre-weight per inch $\left(c \times \frac{8}{3} l \times \frac{1}{w}\right)$	3·87	0·77	20
Clinging power ÷ square root of fibre-weight per inch $\left(\frac{c}{\sqrt{w}}\right)$	0·697	0·068	10

In Table V are given the values of some correlation coefficients between some of the more important fibre-properties. Reference has already been made to the correlation between the clinging power and the highest standard counts. As previously remarked, in considering the clinging power in relation to the strength of a yarn, due allowance has to be made for the fibre length and fibre-weight per inch and when this is done we find that the correlation coefficient between x and cl/w is $+$ 0·60. In other words, the correlation coefficient is comparatively high, and statistically significant. Hence it follows that there is a tendency for those cottons which have high clinging power in relation to their length and fineness to be spinnable to a comparatively high standard count. However, in view of the fact that the correlation coefficient is not higher than 0·60, it is evident that there are many exceptions to this rule. The correlation is decidely less in magnitude than that between the highest standard counts and either length or fibre-weight per inch alone.

Table V

Correlation Coefficients between Clinging Power and Other Properties of Some Standard Indian Cottons

The properties between which the correlation coefficient is calculated	Correlation Coefficients	Standard Deviation
Clinging power and highest standard counts	−0·67	0·08
Fibre-length and highest standard counts	+0·72	0·07
Clinging power per whole fibre and highest standard counts	−0·32	0·13
Fibre-weight per inch and highest standard counts	−0·78	0·06
Clinging power per whole fibre per unit fibre-weight per inch and highest standard counts	+0·60	0·10
Clinging power per unit fibre surface and highest standard counts	−0·10	0·15
Clinging power and fibre-length	−0·41	0·12
Clinging power and fibre-weight per inch	+0·74	0·07
Clinging power per whole fibre per unit fibre-weight per inch and fibre-weight per inch	−0·80	0·06

It has already been pointed out that a rough value of the clinging power per unit fibre surface is obtained by dividing the clinging power by the square root of the fibre-weight per inch; the correlation coefficient between the quantity thus obtained and the highest standard count is only −0·10, which goes to show that even if the clinging power per unit fibre surface is not the same for the different cottons, it is at any rate a property which does not affect the highest warp counts to which a cotton can be spun.

Finally, reference may be made to the correlation existing between the clinging power and certain other fibre properties. Between clinging power and length the correlation coefficient is −0·42 showing that the longer cottons tend to have less clinging power. There is marked correlation between the fibre-weight per inch and the clinging power, whether the clinging power is expressed in the ordinary way or as for the whole fibre divided by the fibre-weight; in the former case the correlation is positive and as high as 0·74, and in the latter case it is negative, but again large, and equal to −0·80 Evidently, therefore, the coarser cottons tend to have higher individual clinging power, but in the yarn the greater number of the finer and longer fibres present offsets the greater individual clinging power of the coarser fibres, so that the finer fibres actually have much higher total clinging power in a yarn of a given count. The relation between individual clinging power and fineness of fibre is well brought out by the target diagram, Fig. 4, showing the the scatter of the different points representing the clinging power and the associated fibre-weight per inch.

VI. CONCLUSIONS

(1) The clinging power depends upon the pressure acting on the fibres, increasing as the pressure increases, though the relative magnitude of the increase is not so rapid as that of the pressure itself.

(2) The cottons which are suitable only for comparatively low counts tend to have a high individual clinging power; it is possible that this property is partly responsible for the irregularity of the yarns spun from them and for the impossibility of spinning them economically to a high count.

(3) There is comparatively high correlation between the highest standard warp counts and the clinging power of the whole fibre per unit fibre-weight

per inch, showing that there is a tendency for those cottons which have high clinging power in relation to their length and fineness to be spinnable to a comparatively high standard count.

(4) The clinging power per unit fibre surface shows less variation than the clinging power or the clinging power of the whole fibre per unit fibre-weight per inch; and it appears that even if the clinging power per unit fibre surface is not the same for different cottons, it is at any rate a property which is unrelated to the highest warp counts to which a cotton can be spun.

(5) The shorter and coarser cottons tend to have higher individual clinging power, but in the yarn the greater number of the finer and longer fibres present offsets the greater individual clinging power of the coarser fibres, so that the finer fibres actually have a much higher total clinging power in a yarn of a given count.

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TECHNOLOGICAL LABORATORY BOMBAY

27th June 1930

34—THE EXAMINATION OF SELECTED COMBED TOPS WITH OBSERVATIONS ON CONTINENTAL MEASUREMENTS

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SUMMARY

The aim of the present work has been to prepare a basis for an international scale of standards for combed tops, at any rate, in so far as the attribute of fineness is concerned. The experimental work consisted in a careful examination of a complete range of tops collected by the Bradford Chamber of Commerce, the British Wool Federation, and the U.S.A. Government. Measurements were first of all made using the mean cross-sectional area of the fibres as the measure of fineness. Later, in accordance with the resolution of the International Wool Conference the measurements on the British tops have been repeated and the results expressed in terms of the weight in milligrammes of 10 metres of fibre at 18¼% regain. The fair agreement between the two methods except for the lowest qualities has been shown and the inadequacy of the weight/length method for these low qualities has been pointed out. For these low qualities the author is of the opinion that the method of cross-sections will prove the more reliable.

The relationship between spinning power and the dimensional attributes of the wool fibre has been the subject of controversy and research for over a century, and attempts hitherto made to relate fibre fineness as expressed by measurement made of its thickness in one direction, that is, its so-called "diameter" have failed to classify wool into categories which could reliably be expected to represent their subsequent manufacturing performance.

It has been shown elsewhere that any system of wool standardisation which does not include some reference to the constitution or structure of the fibre itself cannot possibly express those characteristics and qualities which are essential for manufacturing purposes.

It has often been put forward that a rough classification can be made of the spinning qualities of a class of wool by a measurement of its fineness or thickness, and certainly fineness has a tremendous influence in the subsequent manufacturing performance of the fibre.

Attempts have been made to standardise wool on the basis of fineness alone, and, as already stated, whilst giving a very rough classification, were no real criterion as to its subsequent behaviour.

By the kindness of the British Wool Federation samples of their approved standard tops were placed at our disposal and have been examined from the point of view as to whether a classification of fibre fineness could be made, not expressed as "diameter," but expressed in terms of the area of cross-section of the fibre.

The area of the cross-section of the fibre was taken as a measure of the fineness for several reasons.

(1) Wool is not usually circular in cross-section, in fact in many cases it is almost elliptical, but in reality it is irregular in contour. The only dimensional attribute that can be said to exist with any certainty, whatever the shape of the fibre, is the area of cross-section, and this is definitely measurable.

(2) The area of cross-section is easy to measure, even without a microscope, for it can be simply calculated by weighing a large number of fibres of known length. Secondly, the weight per unit length of the fibre, or length per unit weight, whichever is preferred, gives a quantity which expresses the average thickness of the whole fibre and not the fineness at a single point as in previous work.

The method of measurement developed by Barker and Burgess has been adopted and afterwards checked by the new system due to Herzog. The method adopted obviates any confusion due to the use of the term fibre "diameter" and at the same time gives the distribution of fineness within a sample.

The number of fibres examined in each case was 500, chosen in ten bundles of approximately 50 from widely separated parts of the top. In addition to the cross-sectional area an estimate was made of the ratio of the widest to the narrowest width of the fibre, in other words what might be called the circularity ratio or the degree of ellipticity at any point along its length. These are expressed as a ratio A/B, and give us a measure of the ratio of the major to the minor axis of the ellipse to which the fibre approximates. The nearer this value lies to unity the greater the approach of the cross-section to the circular form.

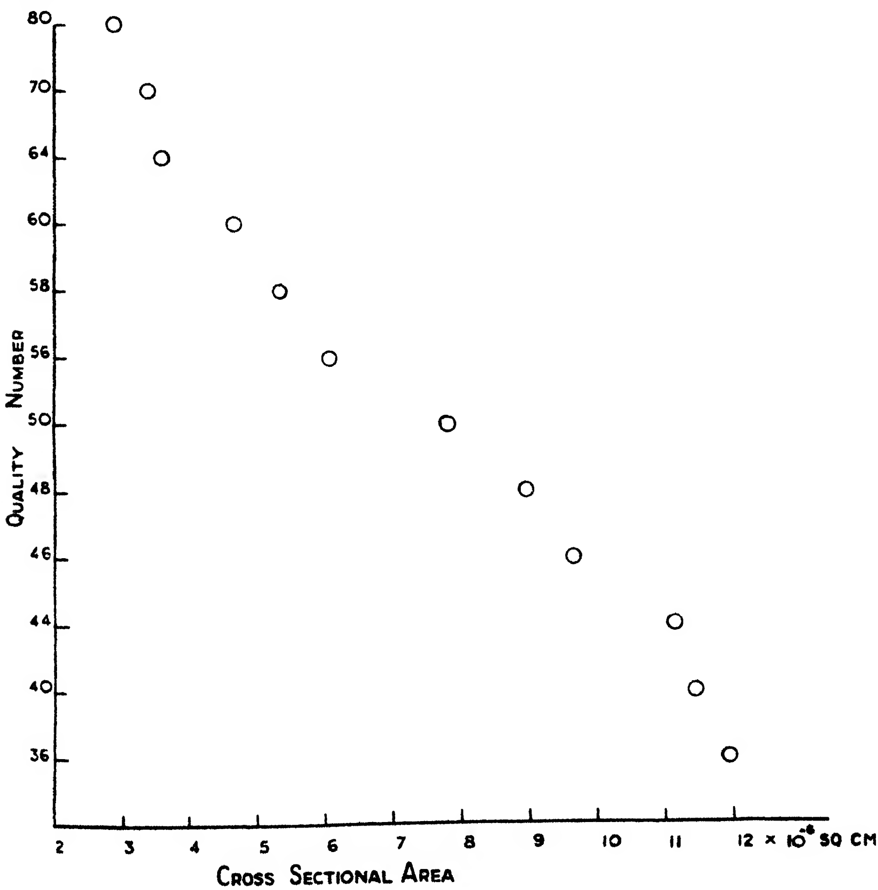


FIG. 1

The results of all the investigations have been collected together in tabular form and may be summarised below—

SUMMARISED TABLE

Quality Number	Mean cross-sectional area $\times 10^{-6}$ sq. cms.	Coefficient of Variation	Mean A/B
80	2·894	39·20%	1·16
70	3·378	37·51%	1·19
64	3·596	38·59%	1·18
60	4·667	45·38%	1·20
58	5·318	45·19%	1·20
56	6·054	41·17%	1·19
50	7·808	41·46%	1·19
48	8·976	38·67%	1·19
46	9·682	36·84%	1·19
44	11·162	40·69%	1·17
40	11·492	36·21%	1·16
36	11·992	42·44%	1·16

Column 1 shows the quality number as assigned by the Wool Federation.
Column 2 the average area of cross-section for each top.
Column 3 shows the coefficient of variation of the fibre thickness within each standard.
Column 4 gives the mean circularity ratio or ellipticity of the fibres in each sample

Fig. 1, which is compiled from columns 1 and 2 of the above table shows in diagrammatic form the relationship of the fineness and quality number. The quality numbers so expressed have only their conventional significance and cannot be used in any quantitative manner for estimation of actual spinning quality. It has been found convenient for purposes of illustration, to space successive qualities equally along the axis of ordinates in one direction, and thereby a limitation is placed upon the diagram, in that it is not intended to represent any mathematical relationship between the two quantities but merely as an illustration to convey to the mind a pictorial representation of the results. It serves, therefore, as a standard diagram with which measurements on other tops may be compared when desired. It will be seen that this method of illustration gives a good curve from which quality numbers can be read off in sequence with fibre fineness.

With regard to column 3, which is a measure of the variation, it is interesting to note that the uniformity of composition of the selected tops as regards fineness is almost the same for all qualities varying very little from one quality to another. The exact manner of variation does not follow any regular sequence or law and these results show that in the selection of the tops great care must have been taken to secure similarity in composition regardless of the quality of the top which was being examined.

The slightly higher values for the variation found in the case of 56's, 58's, and 60's, are in accordance with trade experience.

With regard to the fourth column there is again a great uniformity as regards the contour of the tops in the different qualities. It would seem, therefore, that from the point of view of top composition that the tops are of uniform character.

An examination of the tables was made to ascertain if any irregularity appeared in the size of the intervals of fineness which occur between the different tops as regards quality. As a measure of the variation the percentage increase in the mean cross-sectional area from quality to quality

was calculated and is shown in the table below. The variations appear in quite an irregular and arbitrary manner.

Table A

	80–70	70–64	64–60	60–58	58–56	56–50	50–48	48–46	46–44	44–40	40–36
Percentage increase in cross-sectional area	16·72	6·46	29·80	13·95	13·84	28·97	14·96	7·87	15·35	2·90	4·35

If one takes an interval from 40–44's quality the percentage increase in thickness is only 2·90, whilst taking the same interval from 60–64 it is seen that the increase in area is nearly 30% or actually 29·8%. Again an interval between 64–70 only shows an increase in area of 6·46%. A further comparison may be made in that the percentage difference between the interval 48–50 was a little less than that in the 70–80. It would appear, therefore, that, taken on the basis of area of cross-section, there is no real regularity, with regard to the tops, but at the same time it has to be remembered that the tops selected are typical of those used in the trade.

It seems obvious, therefore, that it is impossible to relate quality numbers, even in the case of selected tops, with their spinning power by any mathematical relation. It has been shown elsewhere by Barker and Norris that contour, that is ellipticity, crimpiness, fibre length and fibre constitution as expressed by the modulus of elasticity must all be considered in fixing a standard system. The present work, however, is valuable, in that it definitely lays down measurements for selected tops based on a definite attribute of the fibre, namely, its area of cross-section. A comparison of these results with those obtained by other workers is of interest—

Table B

Quality	Dantzer and Roehrich. Area	Torridon. Area	Duerden. Area $\left(\frac{\pi d^2}{4}\right)$	Duerden. Area ×A/B
90	2·191	—	—	—
80	2·531	2·894	2·651	3·056
70	2·910	3·378	3·046	3·613
64	3·351	3·596	3·406	4·006
60	3·854	4·667	3·931	4·721
58	4·429	5·318	4·969	5·981
56	5·127	6·054	5·146	6·175
50	5·928	7·808	—	—
48	6·905	8·976	—	—
46	8·121	9·682		—
44	9·621	11·168		—
40	11·490	11·492		—
36	13·988	11·992	—	—

The above table gives some results by Dantzer and Roehrich on a range of French Standard Wools in the grease, and the results obtained by Duerden for the same range of tops as those examined. The comparison is made more difficult, however, on account of the different methods of measurement

employed. Roehrich, for instance, obtains only a mean value for the fineness of the wools, which he measures by weighing a length of 10 metres of fibres, each fibre being cut to a length of 20 mm. On the other hand, Duerden obtains the distribution of fineness in the tops measured, but he makes measurements of diameter at $\frac{1}{8}''$ intervals along the staple, and takes 750 readings in all. To compare these results with those obtained at Torridon it is necessary to convert them to measurements of cross-sectional areas. Even so the results of Duerden are not strictly comparable for two reasons, (1) the assumption of circularity which has to be made is not justifiable, see Table XIII, and (2) the longer fibres contribute more to the final result in Duerden's method than the shorter fibres.

It will be noticed that Dantzer and Roehrich's proposed raw wool standards are lower than the figures obtained for the selected tops at Torridon, but this is not necessarily significant. Such disagreement as exists between the Torridon figures and Duerden's figures can only be explained by the reasons named above, for there seems no reason to believe that there is any serious difference in the accuracies of the two methods as regards the actual linear measurements, or in the relative efficiences of sampling. This view is supported, though by no means proved, by the fact that on multiplying the cross-sectional areas of the fibres by the circularity ratio for the top in question (see column 5), we obtain a value in excess of the area measured directly from cross-sections. Such a result is consistent with the view that the "diameter" measured by Duerden and his workers may

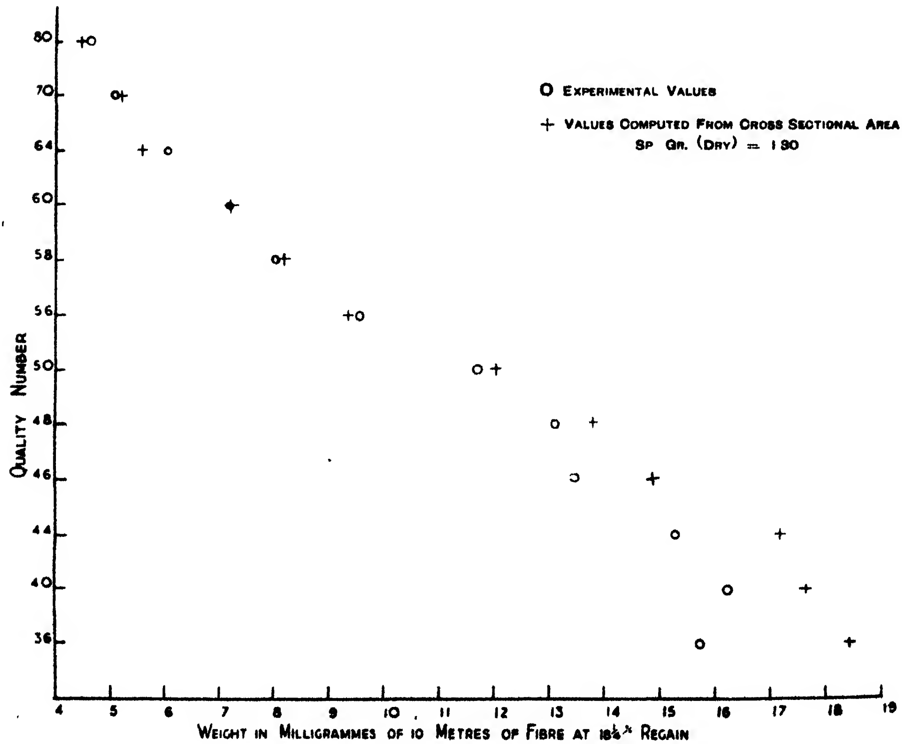


Fig. 2

be either the major or minor axis of the fibre ellipse to which the cross-section approximates, or some other intermediate value.

After completion of the foregoing work it was decided to recommend the international adoption of the method employing the weight/length ratio as the basis for future comparisons of measurements of wool fineness. The British Wool Federation selected combed tops were accordingly submitted to a very careful examination in order to determine the mean fineness expressible in terms of the weight of 10 metres of fibre.

The method consisted in the weighing of a counted number of fibres cut to a definite length. The actual details of the method are as follows. From several places along each top, small samples were taken between the thumb and finger and separated laterally from the top. Care was taken to maintain the fibres in the same relatively parallel position that they occupied in the top. A bundle of fibres of suitable size was then placed in position on the instrument designed for cutting off a fixed length of fibre. Parallelisation of the fibres was finally ensured at this stage, by holding down the bundle of fibres at its middle point and stroking from the middle outwards with a dissecting needle. The bundle was then clamped into position and the fibres cut at the predetermined length.

Clearly the cut length of fibre employed must not be greater than the shortest length of fibre normally occurring in the top, otherwise these short fibres will contribute nothing to the mean fineness, and the result will be vitiated on this account. On the other hand, to cut to a length very much shorter than this is no advantage since by this means the percentage error in the length of the cut fibre is increased, and the number of fibres necessary to be counted out to give a weight ascertainable with the desired accuracy is much augmented, with consequent extra expenditure of time and labour. In the present work the cut length of the fibres from the 36's–50's tops has been 4 cm. and from the 56's–70's, 3 cm., while from the 80's top it has been 2 cm. These lengths it is claimed, are shorter than the lengths of any fibres likely to occur in the respective tops.

The counting operation was simple but somewhat tedious. It consisted in placing the cut bundle of fibres with as little disturbance as possible on to a black velvet board and with suitable forceps, separating fibre after fibre laterally from the bundle and placing them together in a group until the desired number had been counted out. By taking the fibres in turn from the side of the bundle, there was no danger of any preferential selection such as might have occurred if the fibres had been drawn from the end of the bundle. For each quality 2 lots of 500 were counted out and 1 lot of 1,000. The fair agreement between the values obtained for these samples shows the method of sampling to be efficient. Those fibres with either end occurring within the cut interval, will, of course, be shorter than the required length and must be discarded.

The counted groups of fibres were rolled together by the finger into compact bundles and washed in two changes of warm benzene followed by two rinsings in distilled water. In order to assist in the washing a small trace of saponin was present in the first vessel of water. At the same time as the counted groups of fibres were washed, a sample of approximately a gramme from the corresponding top was dealt with in the same manner. All the samples were then exposed together in the same room and allowed to dry for a day or so. The counted groups were then placed in weighing

bottles and the larger sample in a regain bottle, and their weights carefully ascertained on a sensitive chemical balance. The dry weight of the sample in the regain bottle was found in the usual way and the corresponding dry weights of the counted groups of fibres calculated by simple proportion.

The detailed results of the analyses are set out in the accompanying table. The summarised results expressing the mean fineness of the tops in terms of the weight of 10 metres of fibre at a regain of 18¼% are shown in Table C.

Table C

Quality	Length of Fibres	Number of Fibres	Dry Weight in g.	Dry Weight of 10 metres in milligrams
80's	2 cm.	500	·00385	3·85
	,,	500	·00402	4·02
	,,	1,000	·00779	3·89
70's	3 cm.	500	·00636	4·24
	,,	500	·00645	4·30
	,,	1,000	·01273	4·24
64's	3 cm	500	·00758	5·05
	,,	500	·00758	5·05
	,,	1,000	·01549	5·16
60's	3 cm.	500	·00906	6·04
	,,	500	·00897	5·98
	,,	1,000	·01836	6·12
58's	3 cm.	500	·01006	6·71
	,,	500	·00997	6·65
	,,	1,000	·02062	6·87
56's	3 cm	500	·01201	8·07
	,,	1,000	·02437	8·12
50's	5 cm	500	·02419	9·68
	,,	500	·02495	9·98
	4 cm	1,000	·03975	9·94
48's	4 cm	500	·02191	10·96
	,,	500	·02182	10·91
	,,	1,000	·04494	11·23
46's	4 cm.	500	·02255	11·27
	,,	500	·02169	10·34
	,,	1,000	·04663	11·66
44's	4 cm.	500	·02638	13·19
	,,	500	·02579	12·90
	,,	1,000	·05099	12·75
40's	4 cm.	500	·02684	13·42
	,,	500	·02743	13·71
	,,	500	·02801	14·00
36's	4 cm	500	·02734	13·67
	,,	500	·02515	12·58
	,,	500	·02726	13·63

Discussion of Table D

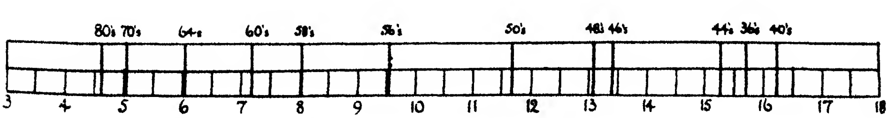
In this table the weight of 10 metres of fibre is the mean weight calculated from the results obtained in triplicate in Table C. The second column gives the weight corresponding to a regain of 18¼% since this is the figure fixed by international agreement for all commercial transactions in combed tops.

Table D

Quality	Weight of 10 metres in milligrams Dry Weight	Weight of 10 metres in milligrams at 18¼% regain	Weight (computed from cross-sectional area) of 10 metres in milligrams Dry Weight	Weight (computed from cross-sectional area) of 10 metres in milligrams at 18¼% regain
80	3·92	4·64	3·76	4·45
70	4·26	5·04	4·39	5·19
64	5·10	6·03	4·67	5·53
60	6·06	7·17	6·07	7·17
58	6·77	8·01	6·91	8·17
56	8·08	9·55	7·87	9·30
50	9·88	11·69	10·15	12·00
48	11·08	13·10	11·67	13·80
46	11·34	13·41	12·59	14·88
44	12·90	15·25	14·51	17·16
40	13·71	16·21	14·94	17·67
36	13·29	15·71	15·59	18·44

It will be noticed that down to the 48's there is a more or less regular gradation of fineness, but that below this quality the successive increments for the weight of 10 metres of fibre are quite irregular. Indeed, at first sight, it would appear that the 40's top is coarser than the 36's which apparently approximates to the 44's in fineness. One has only to look at the tops, however, to see that this is certainly not the case. The real explanation of this apparent inconsistency is that in the lowest qualities varying amounts of strongly medullated fibres are present and, as has been previously shown by Barker and King, the density of these fibres is less than that of real wool substance to an extent depending upon the percentage volume of medullary air space.

In this connection a comparison of this method of measuring fineness with the method discussed in the first part of this paper, becomes of interest. In columns 3 and 4 of Table D, the weights of 10 metres of fibre for the different qualities have been computed using the value obtained for the mean cross-sectional area by the method of cross-sections, and assuming that the specific gravity of wool is 1·30 when dry (vide King, 1926). The agreement between the two sets of values down to the 50's quality is on the whole good, when proper allowance is made for errors of sampling and of measurement. Certainly it may be stated that no support is offered for the doubt some writers have expressed in regard to this method, viz., that the mounted section is not the same as the true dry section of the fibre. The discrepancies between the values for the low qualities one would, of course, expect on account of the presence of the medullated fibres mentioned above. For these qualities one may regard the figure for the cross-sectional area given by the method of cross-sections as the more reliable indication of fineness.



EXPERIMENTAL SCALE OF FINENESS EXPRESSED IN TERMS OF THE WEIGHT IN MILLIGRAMMES OF 10 METRES OF FIBRE AT 18¼% REGAIN

FIG. 3

The discrepancies between the readings for the lowest qualities might constitute an objection to this method as a system for the standardisation of fineness of coarser wool. The results for the 44's, 40's, and 36's show that the weight of 10 metres of fibre can never be the sole criterion of fineness, for, so far as these tops are concerned, such a method would obviously lead to a great deal of uncertainty. For these qualities some other system of measurement must be adopted in addition, as has been done in the present work.

The weight per unit length method, as already pointed out by Roberts, assesses the average fineness of the whole fibre, and not, as in any microscopic method, the area of cross-section at one point of the fibre's length. It is thus impossible, by any microscopic method which examines the fibre merely at one point, to take into consideration those inherent variations in thickness which always occur in the wool fibre along its length. A difference in the results obtained by calculation of fibre thickness from weight per unit length measurements and those values obtained by microscopic measurement is therefore to be expected. It is obvious, however, that, with the limitations mentioned above, the weight per unit length gives the true average value of the fineness of a fibre along its entire length.

Detailed Results

The results of the individual measurements are set out in the accompanying tables. Each table takes the form of a frequency distribution so that the number of fibres having a particular cross-sectional area or circularity ratio may be seen at a glance. The distribution of fibre fineness within each selected top conforms approximately to the normal frequency distribution. The first column in the tables gives the upper limits of the class intervals into which the fibres are grouped, e.g. the class with the upper limit 3 includes all fibres with cross-sectional areas between 2·01 and $3{\cdot}00 \times 10^{-6}$ sq. cms. The second column gives the number of fibres in each class or the frequency. In the third column is written the product (Deviation from the Mean) $\times$ Frequency. For this purpose a working mean is assumed and the correction to be applied to furnish the corrected mean calculated. The fourth column contains values of (Deviation from the Mean)^2 $\times$ Frequency. From these figures are calculated, by the ordinary statistical methods, the standard deviation (σ), the standard error of the mean $\left(\frac{\sigma}{\sqrt{n}}\right)$ and the coefficient of variation $\left(\frac{\sigma}{m} \times 100\right)$. The latter figure gives some idea of the amount of variation of fineness occurring in the top when the mean fineness is taken as the standard for comparison. A high value indicates the presence of fibres both much coarser and much finer than the average while a low value indicates a high degree of uniformity of fineness.

To test the method of sampling one test (56's) was performed in duplicate. Now it may be shown from the theory of statistics that the error in the difference between the means of two samples with standard deviation σ_1 and σ_2 is

$$\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}$$

where n_1 and n_2 are the number of readings in each sample. In this case

$n=n_. = 500$. Also (see Table VI) $\sigma_1=2{\cdot}649$ and $\sigma_2=2{\cdot}493$. Therefore the standard error of the difference of the means is

$$\sqrt{\frac{2{\cdot}649}{500}+\frac{2{\cdot}493}{500}}$$
$$= 0{\cdot}1627$$

It is usual to regard as significant a difference greater than two-and-half times this value. The actual difference found for the means of the two samples drawn by the usual method of sampling from 56's top was 6·062—6·054 i.e., 0·008 or less than 1/20th of the standard error of the difference. The method of sampling therefore was deemed to be satisfactory.

The author would wish to record his indebtedness to his assistant Miss A. L. Walker, for her careful and accurate work in connection with the analyses contained in this paper.

Table I

80's Selected Top. Cross-sectional Area.

Limits 10^{-6} sq. cms.	No of Fibres	μ_1	μ_2
0·5	—		—
1·0	—	—	—
1·5	24	− 72	216
2·0	69	−138	276
2·5	103	−103	103
3·0	121	−313	—
3·5	81	81	81
4·0	43	86	172
4·5	17	51	153
5·0	21	84	336
5·5	6	30	150
6·0	5	30	180
6·5	3	21	147
7·0	2	16	128
7·5	2	18	162
8·0	—	—	—
8·5	1	11	121
9·0	1	12	144
9·5	—	—	—
10·0	—	—	—
10·5	—	—	—
11·0	—	—	—
11·5	1	17	289
	500	457	2,658
Difference ...		+144	
Divided by 500		+·288	5·3160
			·0829
			·0833*
			5·1498
Corrected for class intervals		+0·144	1·2874

Working mean ...	2·750	Estimate of variance	= 1·287
Correction	+0·144	Estimate of standard deviation ...	= 1·344
Estimate of mean ...	2·894	Coefficient of variation	=39·20%
Standard error ...	0·051		

* Sheppard's correction for grouping.

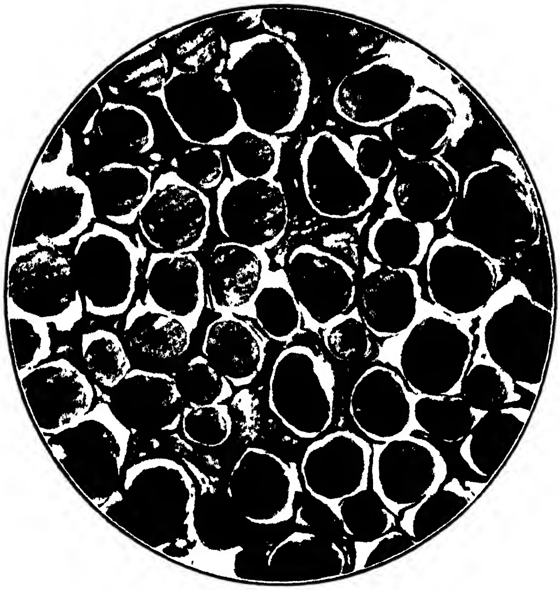
Table II

70's Selected Top. Cross-sectional Area.

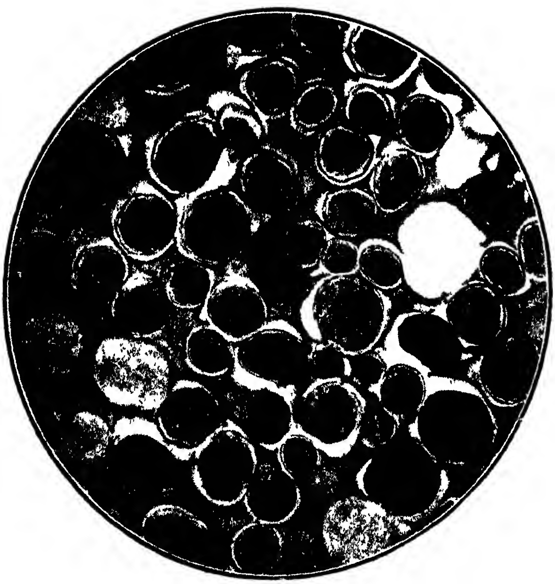
Limits $\times 10^{-6}$ sq. cms.	No of Fibres	μ_1	μ_2
0·5	-	—	—
1·0	--	—	—
1·5	9	−36	144
2·0	42	−126	378
2·5	74	−148	296
3·0	106	−106	106
3·5	73	−416	
4·0	68	68	68
4·5	38	76	152
5·0	40	120	360
5·5	23	92	368
6·0	9	45	225
6·5	4	24	144
7·0	5	35	245
7·5	3	24	192
8·0	2	18	162
8·5	3	30	300
9·0	--	—	—
9·5	1	12	144
	500	544	3,284
Difference ...		+128	
Divided by 500		·256	6·5680
			·0655
			·0833
			6·4192
Corrected for class interval		·128	1·6048

Working mean ...	3·250	Estimate of variance	= 1·605
Correction	+0·128	Estimate of standard deviation ...	= 1·267
Estimate of mean ...	3·378	Coefficient of variation	= 37·51%
Standard error ...	0·057		

PLATE I



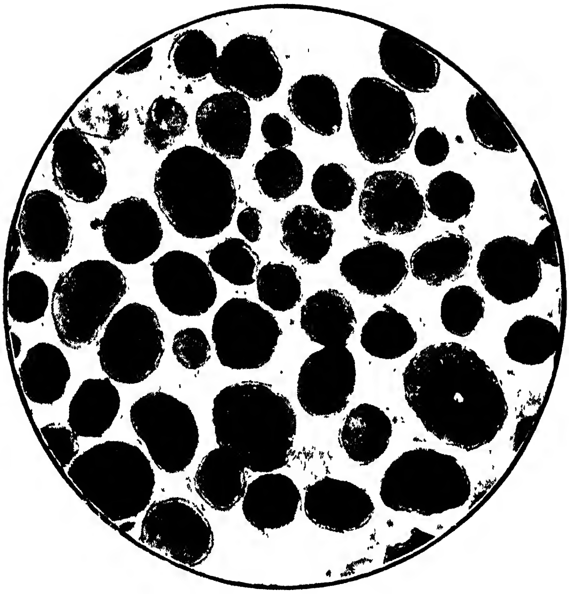
36's



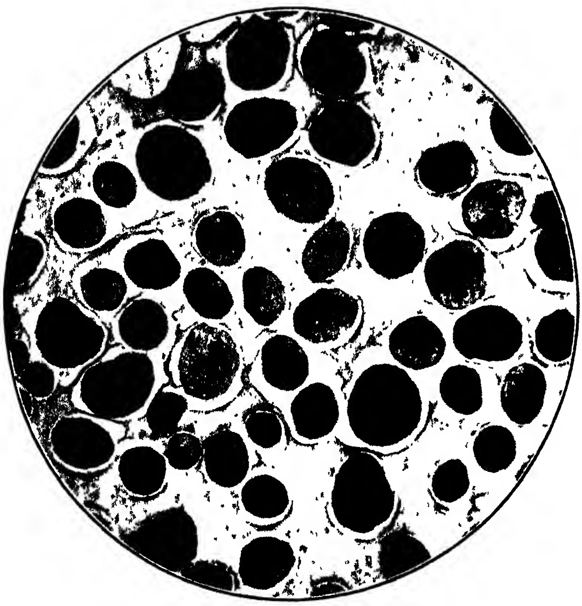
40's

Note the presence of medullated fibres in these low qualities.

PLATE II



44's



46's

Note the presence of medullated fibres in these low qualities.

Table III

64's Selected Top. Cross-sectional Area.

Limits × 10^{-6} sq. cms	No of Fibres	μ_1	μ_2
0·5	-	—	—
1·0	3	−15	75
1·5	11	−44	176
2·0	26	−78	234
2·5	61	122	244
3·0	95	−95	95
3·5	75	−354	
4·0	75	75	75
4·5	39	78	156
5·0	42	126	378
5·5	24	96	384
6·0	19	95	475
6·5	8	48	288
7·0	10	70	490
7·5	3	24	192
8·0	3	27	243
8·5	5	50	500
9·0	1	11	121
	500	+700	4,126
Difference		∔346	
Divided by 500		0·692	8·2520
			·4789
			·0833
			7·6898
Corrected for class interval . . .		0·346	1·9224

Working mean ...	3·250	Estimate of variance	= 1·922
Correction	+0·346	Estimate of standard deviation ..	= 1·387
Estimate of mean ...	3·596	Coefficient of variation	=38·59%
Standard error ...	0·062		

Table IV

60's Selected Top. Cross-sectional Area.

Limits $\times 10^{-6}$ sq. cms.	No of Fibres	μ_1	μ_2
0·5	—	—	
1·0	1	−7	49
1·5	2	−12	72
2·0	11	−55	275
2·5	30	−120	480
3·0	58	−174	522
3·5	58	−116	232
4·0	63	− 63	63
4·5	54	−547	
5·0	44	44	44
5·5	48	96	192
6·0	30	90	270
6·5	14	56	224
7·0	14	70	350
7·5	17	102	612
8·0	5	35	245
8·5	7	56	448
9·0	4	36	324
9·5	6	60	600
10·0	6	66	726
10·5	6	72	864
11·0	3	39	507
11·5	4	56	784
12·0	—	—	—
12·5	2	36	512
13·0	1	17	289
13·5	1	18	324
14·0	1	19	361
	500	964	9,369
Difference ...		+417	
Divided by 500		0·834	18·7380
			·6956
			·0833
			17·9591
Corrected for class interval		0·417	4·4898

Working mean	4·250	Estimate of variance	= 4·490
Correction	+0·417	Estimate of standard deviation ...	= 2·119
Estimate of mean ...	4·667	Coefficient of variation	= 45·38%
Standard error	0·095		

Table V

58's Selected Top. Cross-sectional Area.

Limits $\times 10^{-6}$ sq. cms.	No. of Fibres	μ_1	μ_2
1	—	—	—
2	14	−56	224
3	60	−180	540
4	99	−198	396
5	88	−88	88
6	79	−522	
7	44	44	44
8	42	84	168
9	43	129	387
10	15	60	240
11	2	10	50
12	4	24	144
13	6	42	294
14	1	8	64
15	—	—	—
16	3	30	300
	500	+431	2,939
Difference ...	..	−91	
Divided by 500		−0·182	5·8780
			·0333
			·0833
			5·7614

Working mean ...	5·500	Estimate of variance	= 5·761
Correction	0·182	Estimate of standard deviation ..	= 2·403
Estimate of mean	5·318	Coefficient of variation	= 45·19%
Standard error .	0·106		

Table VI

56's Selected Top. Cross-sectional Area.

Limits $\times 10^{-6}$ sq. cms	1st 500 No. of Fibres	1st 500 μ_1	1st 500 μ_2	2nd 500 No. of Fibres	2nd 500 μ_1	2nd 500 μ_2
1	—	—	—	—	—	—
2	10	−40	160	7	−28	112
3	37	−111	333	37	−111	333
4	84	−168	336	66	−132	264
5	70	−70	70	87	−87	87
6	76	−389		71	−358	
7	59	59	59	69	69	69
8	54	108	216	59	118	236
9	39	117	351	46	138	414
10	29	116	464	23	92	368
11	16	90	450	15	75	375
12	11	66	396	7	42	252
13	8	56	392	6	42	294
14	5	40	320	4	32	256
15	2	18	162	3	27	243
	500	670	3,709	500	635	3,303
Difference		+281			+277	
Divided by 500 .		+0·562	7·4180		+0·554	6·6060
			·3158			·3069
			·0833			·0833
			7·0189			6·2158

	1st 500	2nd 500
Working mean ...	5·500	5·500
Correction ...	+0·562	+0·554
Estimate of mean	6·062	6·054
Standard error ..	0·118	0·112

	1st 500	2nd 500
Estimate of variance	7·019	6·216
Coefficient of variation	43·70%	41·17%
Estimate of standard deviation	2·649	2·493

Table VII

50's Selected Top. Cross-sectional Area.

Limits × 10^{-6} sq cms	No. of Fibres	μ_1	μ_2
1			—
2	4	−24	144
3	18	−90	450
4	34	−136	544
5	42	−126	378
6	52	104	208
7	73	−73	73
8	66	−553	
9	55	55	55
10	43	86	172
11	30	90	270
12	27	108	432
13	17	85	425
14	19	114	684
15	8	56	392
16	7	56	448
17	—	—	—
18	1	10	100
19	2	22	242
20	1	12	144
21	1	13	169
	500	707	5,330
Difference		+154	
Divided by 500		0·308	10·6600
			·0949
			·0833
			10·4818

Working mean ...	7·500	Estimate of variance	=10·482
Correction	+0·308	Estimate of standard deviation ...	= 3·237
Estimate of mean .	7·808	Coefficient of variation	=41·46%
Standard error ...	0·145		

Table VIII

48's Selected Top. Cross-sectional Area.

Limits $\times 10^{-6}$ sq. cms.	No. of Fibres	μ_1	μ_2
1	—	—	—
2	2	−14	98
3	7	−42	252
4	19	−95	475
5	32	−128	512
6	50	−150	450
7	46	−92	184
8	56	−56	56
9	66	−577	
10	46	46	46
11	43	86	172
12	37	111	333
13	24	96	384
14	21	105	525
15	24	144	864
16	9	63	441
17	9	72	576
18	4	36	324
19	—	—	—
20	4	44	484
21	1	12	144
	500	+815	6,320
Difference ...	... .	+238	
Divided by 500 ...		+0·476	12·6400
			·2266
			·0833
			12·3301

Working mean ...	8·500	Estimate of variance	= 12·330
Correction	+0·476	Estimate of standard deviation ...	= 3·511
Estimate of mean ...	8·976	Coefficient of variation	= 38·67%
Standard error ...	0·157		

Table IX

46's Selected Top. Cross-sectional Area.

Limits $\times 10^{-6}$ sq. cms.	No. of Fibres	μ_1	μ'_2
1	—	—	—
2	1	−8	64
3	6	−42	294
4	17	−102	612
5	26	−130	650
6	29	−116	464
7	52	−156	468
8	49	−98	196
9	51	−51	51
10	53	−703	
11	43	43	43
12	50	100	200
13	26	78	234
14	25	100	400
15	24	120	600
16	21	126	756
17	11	77	539
18	9	72	576
19	1	9	81
20	2	20	200
21	1	11	121
22	2	24	288
23	—	—	—
24	1	14	196
	500	794	7,033
Difference ...		+91	
Divided by 500		+0·182	14·0660
			·0331
			·0833
			13·9496

Working mean ...	9·500	Estimate of variance	=13·950
Correction	+0·182	Estimate of standard deviation ...	= 3·735
Estimate of mean ...	9·682	Coefficient of variation	=36·84%
Standard error ...	0·167		

Table X
44's Selected Top. Cross-sectional Area.

Limits $\times 10^{-6}$ sq cms	No of Fibres	μ_1	μ_2
1	—	—	—
2	1	−9	81
3	4	−32	256
4	17	−119	833
5	18	−108	648
6	18	−90	450
7	29	−116	464
8	33	−99	297
9	45	−90	180
10	38	−38	38
11	60	−701	
12	52	52	52
13	34	68	136
14	30	90	270
15	24	96	384
16	36	180	900
17	13	78	468
18	14	98	686
19	8	64	512
20	9	81	729
21	4	40	400
22		—	—
23	2	24	288
24	4	52	676
25	2	28	392
26	3	45	675
27			—
28	—		—
29	1	18	324
30	—	—	—
31		—	—
32	1	21	441
	500	1,035	10,580
Difference ...	..	+334	
Divided by 500	.. ..	0·668	21 1600
			·4462
			·0833
			20·6305

Working mean ...	10·500	Estimate of variance	= 20·630
Correction	+·668	Estimate of standard deviation ...	= 4·542
Estimate of mean ...	11·168	Coefficient of variation	= 40·69%
Standard error .	·203		

Table XI

40's Selected Top. Cross-sectional Area.

Limits $\times 10^{-6}$ sq cms.	No of Fibres	μ_1	μ_2
1		—	
2	—	—	
3	1	−9	81
4	10	−80	640
5	2	−14	98
6	26	156	936
7	30	-150	750
8	36	144	576
9	54	- 162	486
10	35	70	140
11	42	—42	42
12	49	- 827	
13	46	46	46
14	42	84	168
15	41	123	369
16	18	72	288
17	17	85	425
18	16	96	576
19	12	84	588
20	6	48	384
21	4	36	324
22	8	80	800
23	1	11	121
24	1	12	144
25	1	13	169
26		—	—
27	1	15	225
28		—	—
29		—	—
30	1	18	324
	500	823	8,700
Difference ...		—4	
Divided by 500		−0·008	17·4000
			·0001
			·0833
			17·3166

Working mean ...	11·500	Estimate of variance	=17·317
Correction	−0·008	Estimate of standard deviation ...	= 4·161
Estimate of mean ...	11·492	Coefficient of variation	=36·21%
Standard error ...	·186		

Table XII

36's Selected Top. Cross-sectional Area.

Limits $\times 10^{-6}$ sq. cms.	No. of Fibres	μ_1	μ_2
1	—	—	—
2	1	−10	100
3	3	−27	243
4	6	−48	384
5	11	−77	539
6	30	−180	1,080
7	30	−150	750
8	34	−136	544
9	47	−141	423
10	35	−70	140
11	33	−33	33
12	43	−902	
13	38	38	38
14	23	46	92
15	28	84	252
16	28	112	448
17	25	125	625
18	21	126	756
19	13	91	637
20	15	120	960
21	11	99	891
22	7	70	700
23	3	33	363
24	3	36	432
25	5	65	845
26	4	56	784
27	2	30	450
28	—	—	—
29	1	17	289
	500	1,148	12,798
Difference ...	...	+246	
Divided by 500 ...	...	+·429	25·5980
			·2421
			·0833
			25·9234

Working mean ...	11·500	Estimate of variance	=25·923
Correction	+·492	Estimate of standard deviation ...	= 5·092
Estimate of mean ...	11·992	Coefficient of variation	=42·44%
Standard error ...	·297		

Table XIII
CIRCULARITY RATIO

Limits	Frequencies												
	80's	70's	64's	60's	58's	56's		50's	48's	46's	44's	40's	36's
1·00	66	46	38	25	29	33	35	34	30	28	41	44	40
1·05	12	18	26	32	34	42	47	39	57	52	45	48	65
1·10	110	81	86	70	54	71	70	67	74	78	82	75	90
1·15	92	85	87	79	78	68	67	90	70	69	93	90	77
1·20	71	73	69	83	68	68	74	67	70	73	71	62	50
1·25	52	63	72	63	73	60	67	57	61	61	56	45	61
1·30	25	40	41	45	43	46	44	48	36	45	24	34	45
1·35	30	43	37	30	48	29	39	31	30	31	32	26	25
1·40	13	21	16	26	34	25	15	26	31	18	23	15	16
1·45	8	12	8	17	14	26	14	14	10	11	11	10	11
1·50	13	6	12	10	12	11	9	12	12	10	3	6	11
1·55	5	2	3	7	5	7	4	8	4	8	5	3	2
1·60	1	5	—	5	2	6	8	1	4	7	6	1	1
1·65	2	4	1	—	—	2	5	1	5	1	4	3	2
1·70	—	1	2	2	3	1	1	3	4	4	—	—	2
1·75	—	—	1	3	—	3	1	—	2	2	1	—	1
1·80	—	—	1	1	3	—	—	1	—	1	1	—	—
1·85	—	—	—	1	—	2	—	1	—	—	—	1	1
1·90	—	—	—	1	—	—	—	—	—	—	1	1	—
1·95	—	—	—	—	—	—	—	—	—	1	1	—	—
2·00	—	—	—	—	—	—	—	—	—	—	—	—	—
Mean A/B	1·16	1·19	1·18	1·20	1·20	1·20	1·19	1·19	1·19	1·19	1·17	1·16	1·16

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35—A CLOTH WEAR TESTING MACHINE

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SUMMARY

The design of cloth wear testing machines is discussed and a machine embodying several new features is described. Results are given showing the effect of variation of the rubbing conditions on the resistance to wear of a cloth, also results are given comparing the wear resistance under fixed conditions, of a variety of linen cloths.

In all cases examined in the finished state, weft specimens withstand more rubbing than warp specimens, but this is often reversed after laundering when the cloth is in the service state. It is shown that wear tests and tensile strength tests bear little relation to each other.

INTRODUCTION

A machine was required for testing the resistance to wear of linen cloths of varying structures, for comparison with the results of other cloth tests and of actual life in repeated laundering tests. The evolution of a satisfactory wear testing machine is considered to be one of the most important problems in cloth testing. The tensile strength test is a criterion of quality of material but is generally admitted not to bear any close relation to the behaviour in use. Most cloths have to withstand wear by rubbing of one kind or another, between cloth and cloth or between cloth and hard material and a large class of cloths have to withstand wear in laundering due to a combination of effects such as friction and internal stresses caused by the churning action of the washing machines and by constant rearrangements of texture caused by alternate wetting and drying. Obviously no one machine can simulate exactly the variable conditions which may be met with in use, and so it becomes a question of making the most suitable compromise between the reproduction of some practical kind of wear and the general requirements of any laboratory testing machine.

The essential features of a testing machine are reliability and freedom from personal effects; capability of reproduction of results on separate machines; provision for variation under definite control of certain predominating factors; reasonable time occupied in carrying out a test; and quantitative expression of the result. In addition it is a great advantage if the machine can be designed so as to enable a wide range of materials to be tested under the same conditions, thus enabling direct comparisons to be made.

A number of wear testing machines for cloths have been described, but none appear to embrace all the above-mentioned desirable features. They may be broadly classified according to the nature of the wearing surface employed or the method of expressing the result, as follows—

(*a*) Rubbing of cloth against a standard cloth, and noting the time or number of rubs to wear a hole. This was used by Muller[1] and Kapff.[2] Brackett, Floyd, and Dennen[3] used a similar method and determined the loss in strength after a fixed amount of rubbing.

(*b*) Rubbing of cloth against steel surface in the form of rounded narrow blade, blunt knives or knurled cylinders, and determining the loss of strength after a fixed amount of rubbing. Rubbing has been effected both by movement of the cloth and by reciprocating or rotatory motions of the rubbing surface. Machines of this type were used by Hasler,[4] Kapff,[2] Amsler,[5] Smith.[6] Kertess,[7] and Morton and Turner[8] used steel surfaces and also carborundum. Haven[9] used a similar method but a rubbing surface of emery paper.

(*c*) Whatmough[10] used a machine in which the cloth was held in contact with a stationary roller and subjected to repeated blows by small elastic hammers, determining the time for the cloth to become thin and perforated.

Kertess[7] states that in order to get consistent results from scraping machines of the Hasler type, it is necessary to prepare the cloth surface, and he gives details of an elaborate treatment in acid, washings, and extraction with alcohol for the purpose. This, however, does not appear to be entirely sound as the resulting cloth may differ considerably in behaviour from the normal untreated cloth as used in service.

From consideration of these machines it appears that there are two main problems in the design of a wear testing machine. The first is the selection of the rubbing surface. For some special purposes friction between cloth and cloth would undoubtedly give the best representation of practical wear. This method, however, has serious objections for testing purposes; the time of test must be fairly lengthy, and a standard cloth must be used for the rubbing surface in order to get comparative results from different samples on one machine or from the same samples on different machines. It would be a very difficult matter to ensure the regular supply of a standard cloth. To obtain a reasonable time occupied in testing, recourse must be made to a hard rubbing surface. Steel, woods, and natural stones are all very variable and it appears that carborundum is probably the best material; it can be obtained in any desired form in many grades of coarseness; and it gives rapid wear of cloth without very pronounced changes in its own condition.

The second problem is the mode of expression of the test result. A cloth may be given a certain amount of rubbing and the change in appearance of the surface noted; this is unsatisfactory as it does not give a numerical result. Another method is to determine the loss in tensile strength due to a certain amount of rubbing. This gives a definite numerical result, but involves the carrying out of two strength tests in addition to the rubbing and increases the usual uncertainty in the result arising from sampling. In this method also the range of cloths which can be tested under identical conditions is likely to be limited, as the wear action must be adjusted to ensure that the strength after wearing is not too small, otherwise it would not be capable of accurate measurement on the same machine as employed to measure the strength of the original material. It is doubtful whether the figure for "Wearing Power" so obtained would be capable of correlation with the results of wear in practice. In practice cloths are worn by friction accompanied by intermittent stresses and according to the relative severity of the two, wear may be first indicated by a hole or a rent. In the latter case the cloth is weakened by wear until the strength is less than the imposed stress, depending on its particular use. If this is to be related to the loss in

strength following a certain amount of wear, then it would be necessary to assume a simple relation between the amount of wear and the reduction in strength, but this has not been proved. A third method is to determine the amount of wear necessary to produce a hole, but in this case the end point of the test is somewhat indeterminate and liable to personal error. The remaining alternative, to tension the sample to some definite amount, and to record the number of rubs required to produce fracture has been employed by some workers, and on the whole appears to be the most satisfactory. It enables a numerical result to be obtained from the wear testing machine alone, and indicates the wear withstood by the specimen before its strength is reduced to a certain value, and therefore appears to have some similarity with the practical result, at least in some cases.

Work has been in progress for some time with the object of investigating the wear testing of cloths, and an experimental machine was constructed based on these tentative conclusions from general considerations. The object of this paper is to describe this machine and to discuss some of the results obtained relating to various points in design and performance. Comparison between the results given by this machine and other methods of cloth testing will be given in another paper.

DESCRIPTION OF MACHINE

The machine as used at present is illustrated in Fig. 1 in front and side elevations. The cloth specimens are prepared as for strength testing, cut wider than required and frayed down to a standard width, usually two inches. These specimens are fixed in the two serrated screw clamps A_1, A_2. The top clamp is fixed to a horizontal bar B, which is given a reciprocating motion by the connecting rod C and the wheel D, the traverse being adjustable by the position of the crank pin E in the slot F. Weights G are suspended from the bottom clamp to apply tension to the cloth, and the clamp can move vertically between stops H_1 H_2 on the guides K; the clamp slides very freely and can move a few degrees out of the horizontal, but large rotation is prevented by the extension arms and collars L at each end of the clamp.

A carborundum surface rests against the centre of the cloth, and rubbing is produced by the reciprocating movement of the top end of the cloth. The carborundum rubber M is carried at the end of a pendulum N, pivoted on a bar O, the position of which is adjustable in a slot P radial about the line of contact with the cloth. By this means the pressure between the cloth and the rubbing surface can be varied by the position of the pivot bar and the weight on the end of the pendulum. The wheel D is driven by motor through reduction gearing at about 80-85 r.p.m., the revolutions made during a test being recorded on the counter R.

The carborundum rubber mostly used is 120 grade grit in the form of a segment of a circular cylinder. This was prepared from a rectangular block of 120 grade carborundum 2½ inches by ½ inch section, rubbed down against a block of 70 grade carborundum to fit a template cut to the arc of a circle of 1·8 inches radius and length of chord 2½ inches. This surface feels smooth and presents no sharp jagged surfaces, and so should be free from any sudden changes in condition. At the back of the fabric are two vertical stands S supporting a switch T which is operated by the pendulum to stop the machine on breakage of the specimen. The carborundum rubber is held against a wood back by a screw and washer at each end; the wood back is fixed to the

pendulum by two bolts and wing nuts and the setting can always be repeated by holding the wood block against the stands S whilst tightening up the wing nuts.

In carrying out a test, the strip of cloth cut parallel to warp or weft as the case may be, is fixed in the top clamp when in its mid position. The pendulum is lifted and hooked up clear of the cloth on the catch V. The bottom clamp and its attached weights are lifted to the upper stop, the cloth inserted and clamped tight. The pendulum is released and lowered into contact with the cloth, the reading of the revolution counter noted and the current switched on to start the machine. After a period of rubbing the specimen breaks and the machine stops, when the counter is again read, the difference giving a measure of the amount of wear, a to and fro movement being recorded and counted as one rub.

The machine has proved to be reliable in use and the time of testing can be varied very considerably according to the settings adopted. The wear takes place very evenly across the width of the specimen, the horizontal threads being worn away first in the form of very fine fluff, then the exposed vertical threads are partly worn until breakage occurs. The wear is not localised along a line, as the cloth is pulled diagonally off the square with each movement to and fro of the upper clamp, which also has the effect of lifting the botton clamp slightly at each end of the throw; in consequence the cloth is worn over a band of about ½ inch in width, with the largest traverse used (2 inch throw of the crank). The photographs in Plate I show specimens at an early and a late period of the test, and after fracture.

Table I

Wear Tests on "Standard" Cloth.

Specimens, 7 in. × 2 in. 85 Rubs per minute. Traverse top end 2¼ in.

Condition	Tension on Cloth	Pressure on Rubbing Surface	Rubs to Break (recorded)	
			Warp	Weft
	lb	lb		
With impact ...	10	1	5,064	—
Without impact ...	10	1	3,977	7,729
With impact ..	10	1·75	2,428	2,791
Without impact ..	10	1·75	1,360	1,963

The side to side movement of one end of the specimen was adopted as it causes a continual internal movement of the warp and weft threads which is a feature of any practical wearing condition. It has apparently very little effect on the test result by itself, but would tend to destroy any temporary binding effect due to finishing and so may be expected to help in attaining regularity of results. In addition it turns out to be a very effective method, coupled with the curved rubbing surface, for the self-clearing of the fluff formed during wear. The application of pressure between the rubbing surface and the cloth by means of a pendulum held out of the vertical, is very convenient. It was originally employed as it was thought it might be desirable to use very light tension on the specimen during the rubbing period and effect breakage by lifting the pendulum at regular intervals and allowing it to fall sharply on to the cloth to break the specimen, if sufficiently weakened. It was, however, found to be easier to reduce the time of testing by using a

somewhat higher tension on the cloth and allowing the rubber to remain in contact with the cloth throughout the test, so the use of the ballistic effect was not proceeded with.

EXPERIMENTAL RESULTS

A number of tests were carried out to determine the relative effect of variations in the experimental conditions, with the object of testing the behaviour of the machine and establishing the most suitable and convenient test conditions. The cloth used throughout these tests is a stock commercial line, woven plain to a specification from boiled flax line yarn, and finished in the brown state, and will be referred to briefly as the "standard" cloth. All tests were made on samples in air dry condition at 68° F, and 75% R.H.

Use of Impact Effect

Several comparative tests were made in which the test conditions were identical except that in one test the machine was run as described with the rubbing surface resting in contact with the cloth the whole time, and in the other the rubbing surface was lifted away from the cloth at regular intervals by a cam and allowed to fall against the cloth. As designed the carborundum was off the cloth twice as long as it was in contact, and during this interval the oscillation of the top end was maintained. The results obtained are shown in Table I. The machine records a higher number of rubs in the cases when the impact effect is employed, although actually only a third of this number of rubs is effective. Therefore the numbers recorded are really an index of the time occupied in the test and not the number of rubs to break

Table II

Wear Tests on "Standard" Cloth. Specimens 7 in. × 2 in.

Condition	Pressure on Rubbing Surface	Traverse	Rubs per Minute	Tension on Cloth	Rubs to Break	
					Warp	Weft
	lb.	in		lb.		
With impact . .	1·0	2¼	85	5	7,846	15,068
				10	5,064	—
Without impact	2·6	2¼	85	5	6,779	14,053
				10	2,672	5,540
	1·75	4	80	5	1,102	
				10	508	
				15	358	
				20	288	
				30	158	

Evidently if the carborundum was left in contact the whole time and an impact applied to the back of it at regular intervals, the rubs to break could be recorded definitely and the test would be shorter than when the impact effect was not used. Later results showed that this same reduction in test time can be obtained in other ways which do not need any further complication in the structure of the machine, and which have therefore been adopted in preference.

Tension on the Cloth

The effect of varying the tension on the cloth for several different conditions of working, is shown by the results in Table II. The first four lines

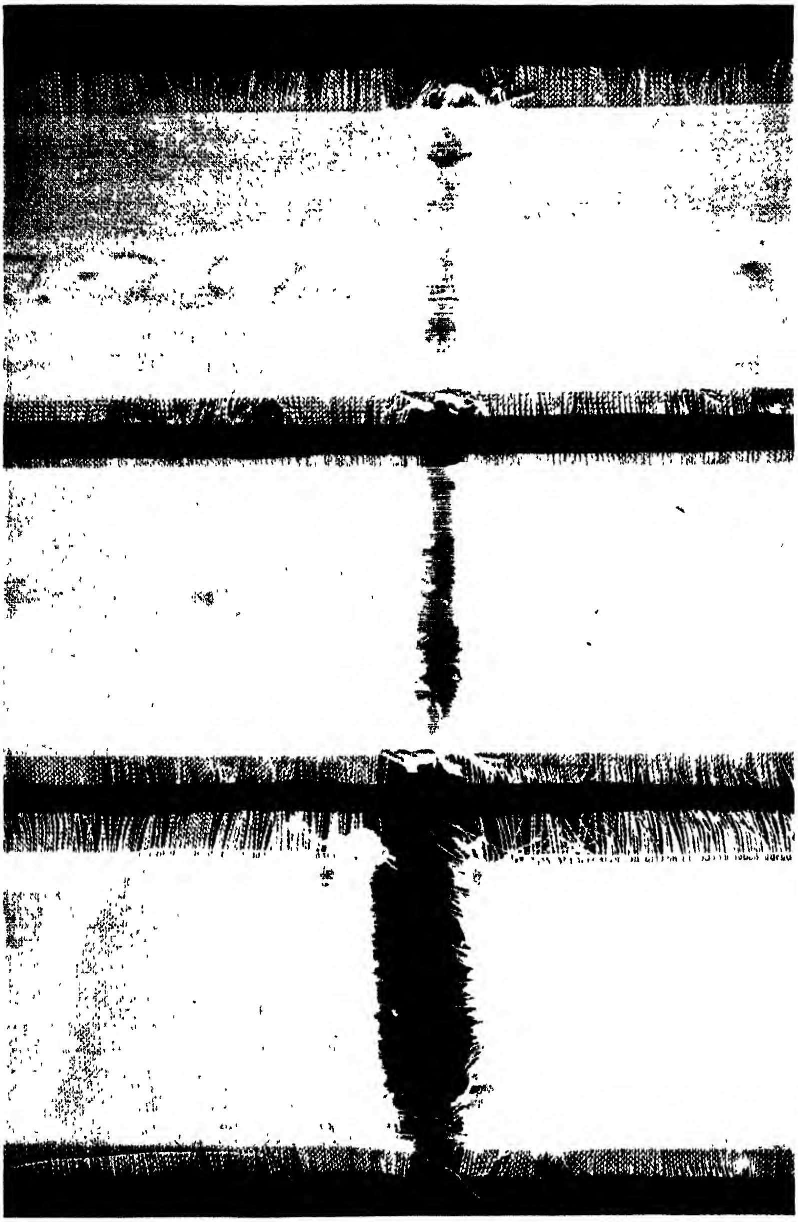

Plate I

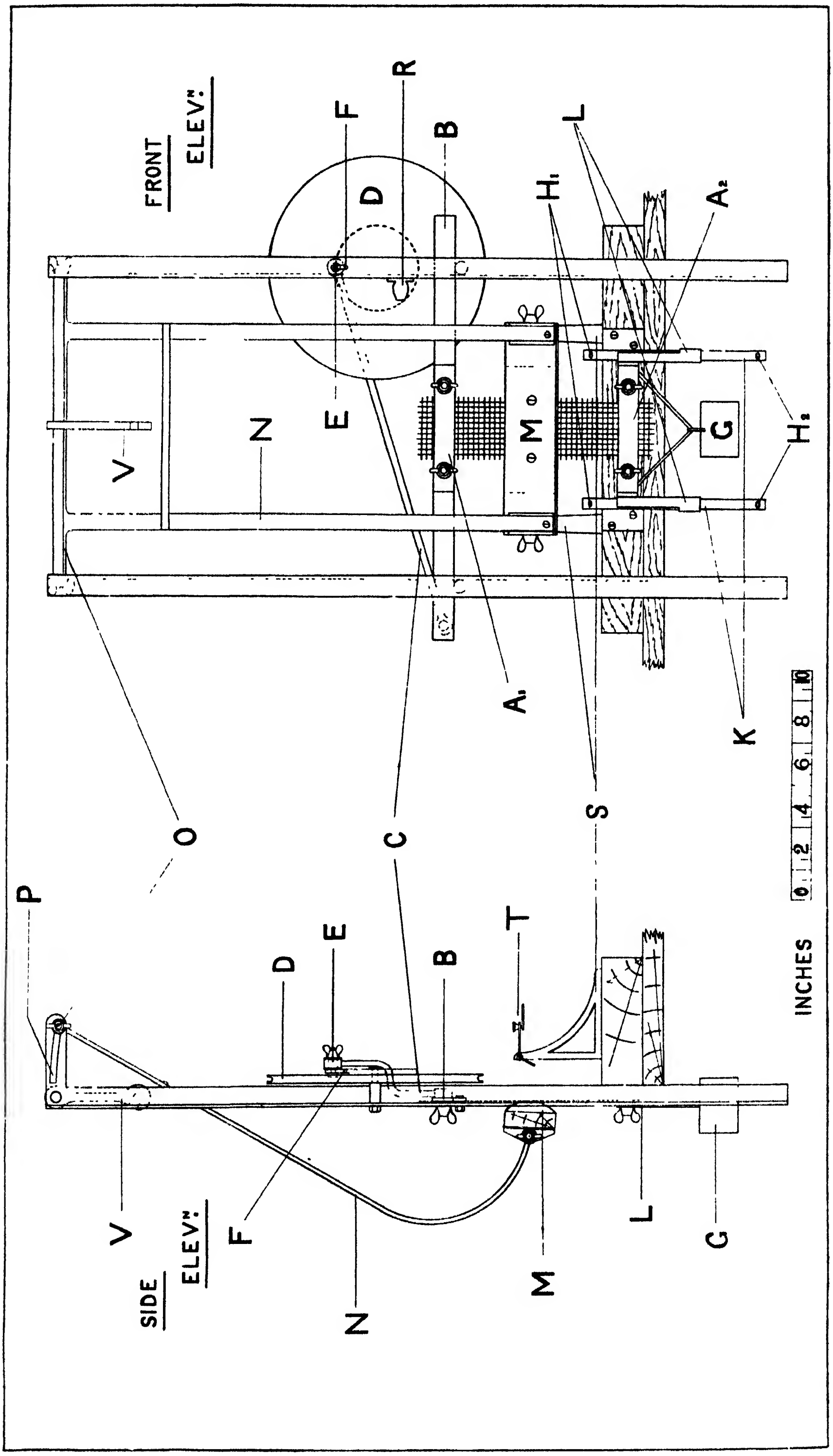

FIG. 1

show that under very similar conditions, increase of tension from 5 to 10 pounds on the 2 inch strip causes a much greater reduction in the time of test when the impact effect is not used. Finally the results of a systematic series of changes of tension on warp specimens for another condition with a large traverse are shown. These results are shown graphically in Fig. 2. As the tension is increased the rubs to break decrease rapidly at first, then more slowly and finally very slowly. The results can be well represented by the smooth curve shown which is drawn from the equation Tension × Rubs = 5,290.

It is concluded from this result that little is to be gained from the point of view of rapidity of testing by applying too high a tension to the cloth, whilst it has the disadvantage of putting the cloth in a very unnatural state. With this standard cloth 15 pounds on a 2 inch strip is ample to give a convenient test, and is also very convenient for a large range of other types of linen cloths. If the relation found above proved to hold equally well for other cloths, then it would enable direct comparison to be made of results obtained from tests with different tensions if this were necessary for some reason.

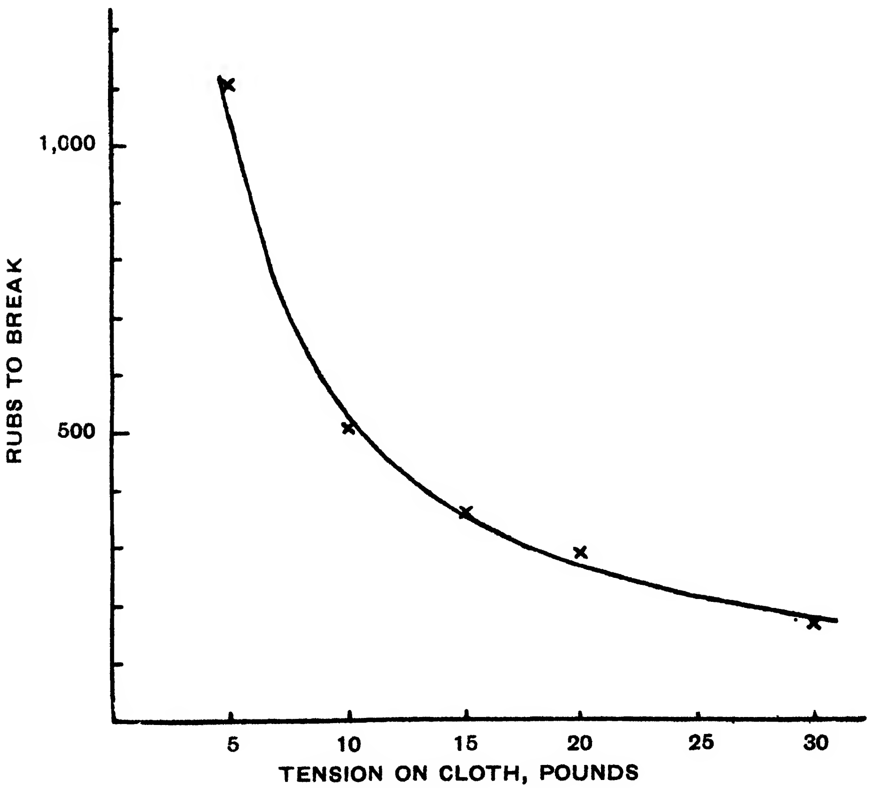

FIG. 2

Pressure between Rubber and Cloth

The effect of varying the pressure between the rubbing surface and the cloth for several tensions on the specimen is shown by the results in Table III. The pressure was varied by weighting the end of the pendulum, and

Table III

Wear Tests on "Standard" Cloth.

Specimens 7 in. × 2 in. 85 Rubs per minute. Traverse top end 4 in.

Tension on Cloth	Pressure on Rubbing Surface	Rubs per Minute	Rubs to Break Warp
lb.	lb.		
5	1·0	97	2,453
	1·75		1,409
	2·6		1,127
10	1·0	95	1,365
	1·75		901
	2·6		849
15	1·0	90	705
	1·75		445
	2·6		392

the pressure was measured by counterpoising the pendulum by weights suspended over a pulley. In these tests the drive of the machine was not altered, and it will be seen that as the loading is increased by increasing the tension on the specimen, the speed of rubbing falls. With each tension, increase of pressure between the rubbing surface and the cloth produces an acceleration in the wear. the rubs to break decreasing with increasing pressure.

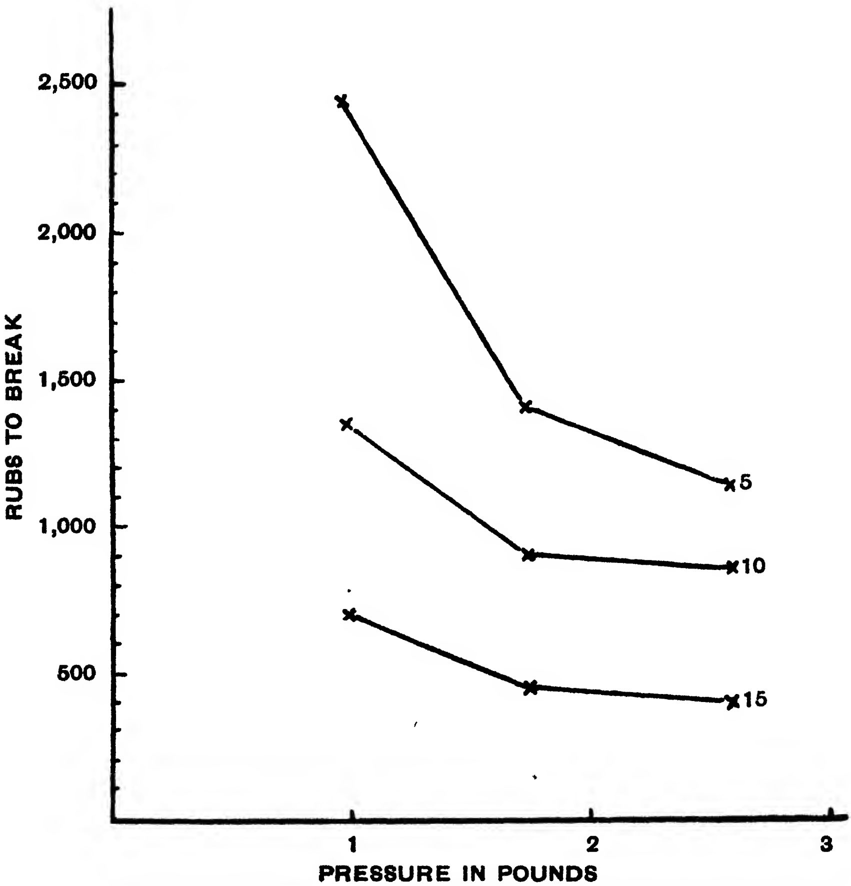

FIG. 3

Table IV

Wear Tests on "Standard" Cloth. Specimens 7 in. × 2 in.
Without Impact—10 pounds tension; 1.75 pounds pressure.

Traverse of Top End	Rubs to Break Warp
in.	
2¼	3,692
2¾	2,381
3⅝	1,330
4	1,068

The results are shown in Fig. 3 and it will be seen that in each case a greater effect is shown by an increase of pressure from 1·0 to 1·75 pounds than from 1·75 to 2·6 pounds, and the effect of pressure decreases as the tension increases. With tensions of 10 or 15 pounds there is not much to gain by increasing the pressure above 1·75 pounds; with a light tension there would be an advantage but an increase in tension is more effective as a means of reducing the time to wear, and also it has the advantage that the specimens keep flatter and show no tendency to ruck down the middle during the reciprocations. A pressure of 1·75 pounds was therefore adopted as a standard figure for subsequent tests.

Traverse of Top End of Cloth

The effect of varying the traverse of the top end of the cloth is shown by the results in Table IV. As the traverse is increased the rubs to break decrease very rapidly. These results are shown graphically in Fig. 4 and they are very well represented by the smooth curve drawn to the equation $RT^2=17{,}250$ where R=rubs to break and T=traverse in inches.

The Carborundum Rubbing Surface

Some tests were made to investigate the effect of grain size and the reproducibility of the carborundum rubbing surface. The original rubbing surface was made as already described from a rectangular block supplied by the Carborundum Co. Ltd., 120 grit bond E 6. This was used continuously for a considerable time, when a further supply of blocks was obtained and five new rubbing surfaces were prepared to the same shape, three of 120 grit and two from the coarser 70 grit. These were fixed in the machine in turn and a wear test made on warp specimens from one cloth. The surfaces were freed from carborundum dust as much as possible by rubbing with a cloth, and then each was allowed to fray through five specimens before recording the average of the next five specimens as shown in Table V. Generally with a new surface the first two or three specimens are worn through with a low number of rubs, but after that the values settle down. The various new surfaces give results in fairly good agreement, considering that sampling variations are also included, and as will be shown these may be considerable. The surface which had been in use for a long period gave a higher result than the similar new surfaces, but it is evident that the rate of change must be fairly small.

The carborundum rubbing surfaces prepared from the coarse grit blocks give a less rapid wear than the surfaces prepared from the finer grit. It must therefore be assumed that the wear takes place at the edges of the ground-down crystals, as there will be a greater number of such sharp edges

on the surface from the fine grit than from the coarse. In the work which has been done, the surfaces have not been washed or brushed between tests as the arrangement appears to be self clearing. If tests were made on cloths finished with wax or oil mixtures, then it might be necessary to wash the surfaces between tests.

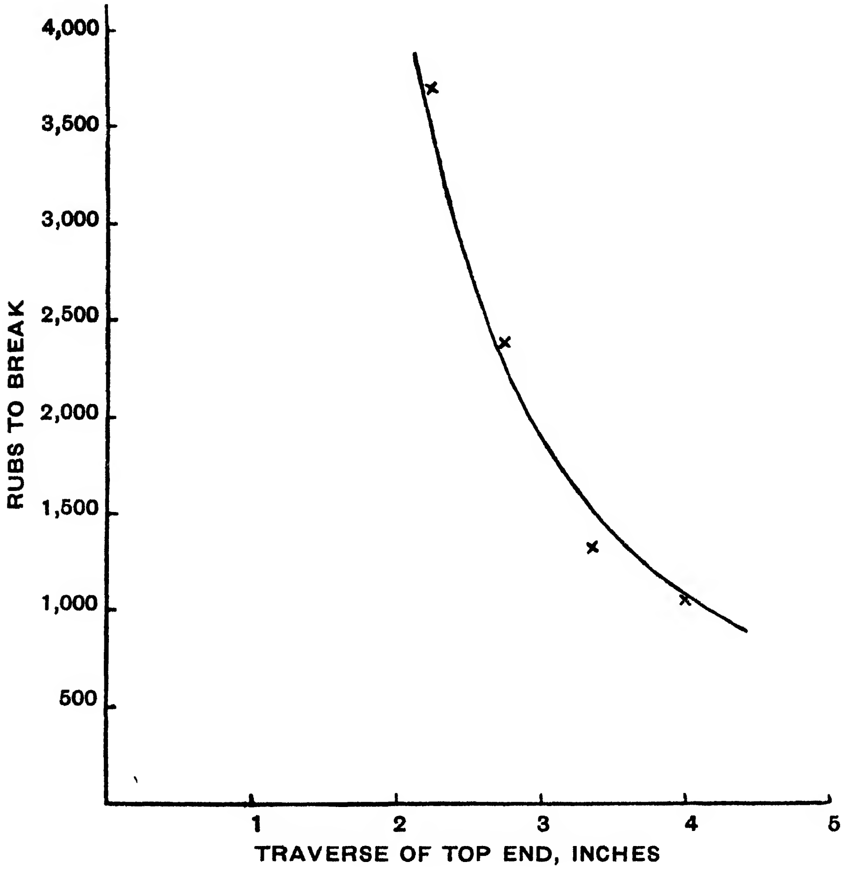

FIG. 4

Regularity of Cloth

Most of the tests recorded were made on five warp or weft specimens cut from the cloth close together. Generally the values obtained are fairly regular, all values lying within say $\pm 20\%$ of the average. In some tests one extremely low or high result may be obtained. Four samples of the "standard" cloth from different sources were examined for regularity by making tests on five specimens cut close together, and repeating either on the two sides of the cloth, or at different places along the length. These tests were made with the first test conditions used, light tension and pressure and with the impact effect, which accounts for the high values. The results are shown diagrammatically in Fig. 5. One of the most striking points is the great variation in the average of five tests from different regions. Similar tensile strength tests or ballistic (work to break) tests would generally agree

to within 10% so that this wear test shows the cloth as much more irregular than the other tests. The average wear results for the samples in Fig. 5 and for an additional sample are compared in Table VI with the average strength tests of these samples, tested in the air dry condition. In three of the four samples the weft tensile strength is less than the warp strength, but in each case the weft resistance to wear is greater than that of the warp. The wear test shows much greater differences between the different cloths than does the strength test, and there is no apparent relation between the two results. Thus samples Nos. 2 and 4 are about equal in strength but No. 4 had 2–3 times the resistance to wear. Again No. 1 was the weakest cloth, but had greater resistance to wear than No. 2, the strongest cloth.

STANDARD CLOTH

Sample 1

WARP 6249	WARP 7561
WEFT 6683	WEFT 9967

Sample 2

WARP 6121	WARP 4321
WARP 5147	WARP 3820
WEFT 3094	WEFT 5743

Sample 3

WEFT 12572	WARP 6618
WARP 8906	WEFT 11595
WEFT 17097	WARP 7929
WARP 7932	WEFT 19007

FIG. 5

It appears therefore that the wear test measures some property of cloth which is not measured in a tensile strength test. It is capable of showing differences between different cloths or between different regions of the same cloth in the finished condition, which would not be revealed by the other tests. Whilst this adds greatly to its value and shows the necessity for the wear test, it also makes the question of sampling more difficult. To obtain a fairly accurate estimate of the resistance to wear of a cloth, it would evidently be necessary to test specimens from several regions. If the test is to be used as a routine or specification test, then time of testing and the amount of cloth used up must both be considered. It is suggested that an average resistance to wear of finished cloth deduced from 12 warp and 12 weft specimens would be satisfactory, each selected in four groups of three from different regions to cover the full width of the cloth.

Table V

Wear Tests on "Standard" Cloth. Specimens 7 in. × 2 in.
Without Impact—15 pounds tension; 1.75 pounds pressure. 85 Rubs per min.
Traverse of top end 4 ins.

Carborundum Surface			Rubs to Break Warp
Block No.	Grade of Grit	Bond	
1 (much used) . . .	120	E 6	358
2 new	120	E 6	328
3 ,, ...	120	E 6	287
4 ,, ...	120	E 6	307
5 ,, ...	70	E 6	832
6 ,, ...	70	E 6	858

Table VI

	Standard Cloth Sample No.			
	1	2	3	4
Average rubs to break—Warp	6,905	4,852	7,846	9,217
Weft	8,325	5,423	15,068	15,591
Breaking strength in pounds—Warp ..	167	186	157	187
Weft .	148	175	181	171

Wear Test on Various Linen Cloths

From the preceding tests discussed, standard test conditions were adopted as follows—

Tension on specimen—15 pounds.
Pressure on surface—1·75 pounds.
Rubs per minute—85.
Traverse of top end—4 inches.
Carborundum—120 grit in contact with cloth throughout the test.
Specimens—7 inches × 2 inches between jaws.

A variety of commercial types of linen cloth were tested under these conditions, and the results appear to be satisfactory, enabling a wide range of cloths to be tested expeditiously under the same conditions. In the case of heavy ducks, the same conditions could be used with specimens 1 inch in width instead of 2 inches. The results obtained on a few types of cloth are shown in Table VII, together with cloth weight, thickness, and strength.

The samples were all tested in the finished state and it will be seen that in every case the weft specimen gave a higher result than the warp specimen; in some cases the tensile strength of the weft was lower and in some cases greater than that of the warp.

Samples Nos. 7 and 8 were tested under double the tension of samples Nos. 1–6 and so the recorded rubs should be doubled to be comparable with the others. In a general way the number of rubs to break increases with the weight and thickness of the cloth. Sample No. 3, however, provides a very striking exception, showing a resistance to wear out of proportion to its thickness, weight, or strength; this is a fine closely woven cloth, but further work is required before a definite explanation of this result could be given.

Table VII

Wear Test on Various Linen Cloths. Specimens 7 in. × 2 in. 15 pounds Tension, Carborundum Block No. 1; 1.75 pounds pressure without Impact. 85 Rubs per minute. Traverse of top end 4 ins.

Sample No.	Description	Weight ozs./sq. yard	Thick-ness mm.	Breaking Strength. *lb on 2 in. Strip*		Rubs to Break	
				Warp	Weft	Warp	Weft
	FINISHED FABRIC						
	FULL BLEACH						
1	Sheer $15^{\circ\circ} \times 14$...	1·88	0·11	101	58	81	90
2	Cambric $14^{\circ\circ} \times 14$	2·77	0·13	152	81	133	175
3	Shirt front linen $16^{\circ\circ} \times 17$ ...	3·33	0·13	172	123	1,823	2,527
4	Damask honeycomb $12^{\circ\circ} \times 12$	7·27	0·35	167	158	535	993
	HALF BLEACH						
5	Plain huck $8^{\circ\circ} \times 5$	8·69	0·51	256	205	907	1,587
	BOILED						
6	Aeroplane linen	3·9	0·185	157	181	357	364
7	Canvas duck (52 × 27) ... (1 in. strip)	15·4	0·670	458	615	803	2,470
8	,, ,, ,, ...	16·1	0·652	424	537	1,033	3,090

It might appear from the fact that in many different types of weave the weft specimens have a higher resistance to wear by rubbing than warp specimens from the finished cloth, that whether the cloth is rubbed with the warp or the weft under tension, a greater proportion of the wear is taken by the warp threads; the warp would be weakened and so give way under the tension in warp specimens, whereas in weft specimens the strength of the weft threads under tension would be conserved for a longer time. This, however, does not appear to fit in with the fact that in finished cloth the warp threads generally lie straighter than the weft threads, so the latter would be more in the surface of the cloth and would be expected to receive the greater amount of wear. A few tests have been made to investigate this point further. Warp and weft wear tests were made on samples of one fabric, made from 25's tow, $\frac{3}{4}$ white, $8^{\circ\circ} \times 8$ in the loom state, finished and twice laundered conditions; in the loom state cloth the weft threads lie straighter than the warp, but in the other two states this condition is reversed. Further tests were made on two of the samples from Table VII after twice laundering. In the latter cases there is only slight change in the relative bending of warp and weft, but the laundered cloth would be more lightly finished (i.e. less compressed). The results are given below—

	Rubs to Break	
	Warp	Weft
25's tow, $8^{\circ\circ} \times 8$, loom state	**1,238**	**1,508**
,, ,, finished	**1,353**	**1,436**
,, ,, twice laundered	**624**	**481**
Sheer from Table VII, twice laundered	**115**	**88**
Shirt front linen, twice laundered	**1,473**	**1,711**

In the 25's tow cloth the resistance to wear of the weft was greater than that of the warp in the loom state and finished conditions, but the warp was stronger than the weft in the laundered cloth. In the sheer also, after laundering the warp gave the higher wear test but with the shirt front linen the weft still retained some of its superiority after laundering. The results show, therefore, that in laundered cloth the warp or weft may be the stronger according to the type of cloth. It may be noticed that with the 25's tow cloth, the resistance to wear of the laundered cloth (unstarched) is very much lower than that of the finished cloth (unstarched) or of the loom state. The resistance to wear of the shirt front linen also decreased considerably on laundering.

This appears to show that the results of the wear tests cannot be explained entirely in terms of the relative crimping of the warp and weft threads, but the state of compression of the yarns must also be considered. Evidently much further work is required before a complete explanation could be given. It is very clear from this work that wear tests on new finished cloth are liable to give an entirely wrong conception of the wearing power of the same cloth when in the service condition.

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June 1930

CORRIGENDUM

31—CRIMP IN WOOL AS A PERIODIC FUNCTION OF TIME

By MABEL H. NORRIS, M.Sc., and P. J. J. VAN RENSBURG B.Sc.
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On page T485, line 6 of the footnote, an error occurs. The word *fibres* should read *crimps*.

THE JOURNAL OF THE
TEXTILE INSTITUTE
TRANSACTIONS

36—THE FOUNDATIONS OF YARN-STRENGTH AND YARN-EXTENSION

PART IV—THE INFLUENCE OF YARN-TWIST ON THE DIAMETERS OF COTTON YARNS, AND ON THE PROPORTIONS OF FIBRE-SLIPPAGE AND FIBRE-FRACTURE IN YARN-BREAKAGE

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SUMMARY

Experiments are described to ascertain the relation between the strengths of yarns prepared with different degrees of twist, and the relative proportions of fibre-breakage and fibre-slippage which occur at yarn-breakage. Measurements have been made on the five cottons, 1027 A.L.F., Punjab-Americans 4F and 289F, Umri Bani, and Nandyal 14, in three different counts, viz., 20's, 30's, and 40's; and on Mollisoni in 10's counts. The tests were made on specimens of yarn 3 inches long; each test-piece was given a certain twist; its breaking strength, its weight, and the numbers of fibres breaking and slipping respectively at yarn-breakage were determined, and also the fibre-weight of the fibres constituting the yarn. Measurements were also made of the diameters of the yarns at the different degrees of twist. Each cotton was spun in the form of mock-grandrelle yarn to permit of the twists being counted in the 3-inch specimens of yarn by means of a lens. A testing-machine is described which was adapted from a twist-testing machine and used for inserting or removing any desired amount of twist, and also for determining the strength of the yarn. Experiments were made at nine different degrees of twist, viz., from 10 to 90 turns per 3-inch length, at intervals of 10 turns. Twenty specimens were tested at each degree of twist; only specimens were selected which appeared to the eye to be regular in diameter throughout the 3-inch length.

The following conclusions are drawn from these experiments—

(1) The diameter of a cotton yarn of a given twist per inch (n) and count (c) falling within the 20's–40's range can be obtained by substituting the values for the counts and twist in one of two formulæ, neither of which contains any arbitrary constants. The simpler formula, that the diameter in millimetres equals $1{\cdot}9/\sqrt{c}.\sqrt[4]{n}$, applies over the practical range of twists, but not at low twists.

(2) A cotton-yarn suffers only a slight change in diameter when it is placed under tension.

(3) The distribution of twist in a yarn of varying diameter is such that the number of turns of twist in any part of the yarn is approximately inversely proportional to the number of fibres in that part; as a consequence of this unequal distribution of twist, the diameter of the yarn at any given cross-section is directly proportional to the number of fibres at that cross-section.

(4) When only uniform specimens of yarn are tested for strength, the strength of the single yarn increases with the twist in 10's to 40's yarns until 30 turns per inch have been inserted. The most rapid increase for 20's and 30's yarn is between 7 and 17 turns per inch; for 40's yarn the most rapid increase of strength is between 10 and 13 turns per inch. The influence of twist is so small at low twists that up to 7 turns per inch the breakage of the yarn takes place almost entirely by fibre-slippage.

(5) The maximum yarn-strength values of the individual cottons do not reflect their highest suitable warp counts; it is therefore concluded that some of the fibre-properties are important not so much for the strength they confer at the place of breakage as for the fact that they determine the frequency and degree of thick and thin places in the yarn.

(6) There is a very close relation between the percentage of fibre-fracture and yarn-strength, over 60% of the fibres breaking at high twist when the yarn-strength is at its highest, and very few fibres breaking at low twist when the yarn-strength is very small indeed.

(7) The values for the percentage of fibre-strength utilised, as calculated from the single-thread strength in relation to the product of the fibre-strength and number of fibres in the cross-section, show that in some cases the percentage actually exceeds 100. The existence of these high values is attributed to the deliberately biassed selection of the specimens of yarn used in the testing, by virtue of which full scope is given for the display of the accession of strength possible by doubling together a number of fibres whose strength varies greatly along their length.

I—INTRODUCTION

It has been pointed out that in previous parts[1,2] of this series of papers that the proportions of fibres which slip or break respectively when a yarn is broken are dependent upon the degree of twist in the yarn; this was clearly shown by the photographs given in Part II[3]. In order to study the matter in its quantitative aspect, advantage has been taken of the method introduced by Miss Clegg[4] and based on Bright's method[5] of staining with congo red to distinguish the ends of broken cotton fibres. While Miss Clegg's work is conclusive that, in ordinary yarns, breakage of a high percentage of the constituent fibres is invariably associated with the yarn-breakage, yet her results do not show at what degree of twist the fibre-breakage begins to predominate over the fibre-slippage. It seemed likely, therefore, that a systematic investigation of the proportions of fibre-breakage and fibre-slippage in yarns which were similar except in their degree of twist, would throw light not only on the dependence of yarn-strength upon fibre-strength, but also upon the various other factors upon which yarn-strength depends. In order to attain this end, measurements have been made of as many characters as possible, both of yarn and fibre, on six cottons chosen to cover a wide range of quality and species; the tests were made on specimens of yarn 3 inches long; each test-piece was given a certain twist; its breaking strength, its weight (counts), and the numbers of fibres breaking and slipping respectively at yarn-breakage were determined, and also the fibre-weight of the fibres constituting the yarn.

II—MATERIALS AND METHODS

(a) Materials

The experiments have been carried out on the following six standard Indian cottons -Surat 1027 A.L.F., Punjab-Americans 4F and 289F, Umri Bani, Nandyal 14, and Punjab-American Desi Mollisoni, all six cottons being

of the season 1926-27. Table I shows the chief fibre-properties of these cottons, as extracted from "Technological Reports on Standard Indian Cottons, 1930."[6] One cotton, Mollisoni, was spun in 10's counts only, whereas each of the other cottons was spun in 20's, 30's, and 40's counts.

Table I

Fibre properties

Cotton (1926–27)	Botanical species	Province or State of growth	Fibre-length (in.)	Fibre-weight per inch (10^{-6} oz.)	Fibre-strength (oz.)	Fibre-rigidity (oz.–in.[2] $\times 10^{-6}$)	Ribbon-width (10^{-3} in.)	Convolutions per inch	Highest warp counts
1027 A.L.F	*Gossypium herbaceum*	Bombay ...	0·97	0·200	0·171	0·162	0·73	96	32
P.A. 4F ...	*G. hirsutum*	Punjab ...	0·78	0·134	0·132	0·093	0·70	104	24
P.A. 289F	,,	,, ...	0·97	0·098	0·109	0·053	0·62	88	40
Umri Bani	*G. indicum*	Hyderabad	0·81	0·200	0·186	0·160	0·67	65	24
N. 14 ...	,,	Madras ...	0·93	0·191	0·223	0·142	0·61	46	34
Mollisoni...	*G. indicum Mollisoni*	Punjab ...	0·68	0·272	0·164	0·242	0·77	65	8

Perhaps the most important feature of these tests is that they have been carried out on yarns of which the twist was accurately known, and was in fact predetermined for each test specimen. The method commonly employed to determine the twist necessitates the removal of the twist and consequently the destruction of the yarn. In order to avoid this the experiments have been conducted on mock-grandrelle yarns of each cotton. For this purpose and for the production of such yarns, a small quantity of each cotton was dyed with direct black; a mixing was then made consisting of one part black-dyed cotton and three parts of the same raw cotton. This mixing was used for one roving, and in order to make the mock-grandrelle, the spinning was carried out from double roving, one roving being of the black mixing and the other of the original raw cotton. It will thus be observed that the spun yarn contained equal proportions of the black mixing and of the raw cotton, so that the yarn itself consisted of one-eighth of the black-dyed cotton and seven-eighths of the original raw cotton. The presence of the dyed cotton did not occasion any trouble in the various processes of spinning. To all intents and purposes, therefore, the yarn on which the experiments were made may be taken to refer equally well to yarns spun direct from double roving from the raw cottons alone. A preliminary experiment had shown that at this degree of dilution of the black cotton it was possible to count without difficulty, with the help of a lens, the twist of the mock-grandrelle yarn.

(b) Methods

The routine followed in a test was as follows—A 3-inch piece of yarn was selected and fixed in the jaws of the testing machine; the twist present in the yarn was counted directly; twist was then inserted in or removed from the yarn according as was necessary to leave the yarn with the exact number of turns of twist desired; next, the yarn was broken at a constant rate of loading, the breaking strength being recorded, and also the extension for 289F in all counts at 90, 60, and 30 turns per three inches respectively. After this, the two broken pieces were cut off at their points of insertion in the jaws, and weighed; and finally, counts were made of the numbers of fibres which had slipped and broken respectively in the rupture of the yarn.

Experiments were made at nine different degrees of twist, viz., from ten to ninety turns per 3-inch length, at intervals of ten turns. Twenty specimens were tested at each degree of twist. Separate experiments were made for the determination of the fibre-weight per inch of the given cotton. Some details of this routine will now be given.

Selection of test-pieces—In these experiments it was desired to minimise as far as possible the effects of irregularity of yarn. The selection of test-pieces was therefore deliberately biassed, and was restricted to portions of yarn which appeared to the eye to be of even diameter. This was one reason why the length of test-piece was restricted to 3 inches, as for lengths greater than this some degree of unevenness cannot be avoided; even in this case it was necessary to reject intervening lengths of yarn of anything from 6 inches to 54 inches long. A second advantage of using short lengths was the ease of manipulation, especially in the initial counting of the twist in the particular test-piece.

Testing machine—As it was desired to insert twist in a specimen or remove twist from it after fixing it in the testing machine, a yarn testing machine of the ordinary type could not be employed.

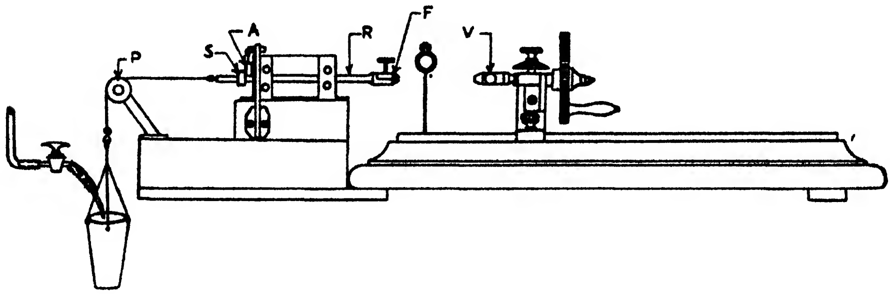

FIG 1

A Goodbrand Twist Tester was adapted for the purpose of these experiments, as indicated diagrammatically in Fig. 1. The movable pillar supporting the twist wheel, and the spindle, revolving jaw, and counting device were retained; the fixed pillar supporting the fixed jaw was removed and in its place there was substituted the arrangement shown in Fig. 1. The second jaw F is fixed to a rectangular iron rod R which passes between small steel rollers mounted on cone bearings suitably supported. To the other end of this rod is attached a string, which passes over the pulley P and supports a very light aluminium pan which can be suitably loaded with small weights as desired. The pan arrangement was used only for very soft-twisted yarns having a very low breaking load; for harder-twisted yarns the pan was replaced by a light aluminium tumbler and the load applied by running water into the tumbler at a practically constant rate (2 grams per second); the tumbler arrangement could not be used for the soft-twisted yarns having only 10 or 20 turns per 3 inches, as for such yarns the weight of the tumbler itself approximated to or greatly exceeded their breaking load. As previously mentioned, all tests were made on 3-inch lengths of yarn; in order to save time in regulating the length of the specimen, the rod R carried a stop; another stop A was carried by one end of a jointed arm, having its other end fixed to the wooden base, so that it could be swung into position to rest on the rod between the stop S and a

plate of the housing of one pair of rollers. When the second stop rested on the rod, and the rod was moved so that the second stop was jammed between the first stop and the plate, the distance between the jaws of the machine was exactly 3 inches. The necessity for having the stop on the swinging arm arises from the fact that the insertion of additional twist in the yarn causes it to contract, and by removing the second stop A after fixing the specimen in position the necessary provision for the take-up of the yarn is made without setting up any additional tension in the yarn itself.

Experimental procedure—A three-inch length of the mock-grandrelle yarn is fixed in the jaws of the testing machine; the free end of the yarn on the bobbin is held in a spring clip to prevent it untwisting. The number of turns of twists in the 3-inch length is counted, and twist is inserted or removed until the number of turns is that desired. The yarn is then tested for strength. The broken pieces of each yarn-specimen are measured, and the length of each broken half affected by the break is calculated from the increase in length; these pieces of yarn are preserved for the subsequent microscopical examination. After staining with congo red, the numbers of broken-fibre ends, cut-fibre ends (if any), and apical ends, are determined for each broken piece. Due allowance has to be made for the number of naturally-occurring broken fibres, which was originally determined in the following manner—for the Punjab-Americans, 4F and 289F, the number of naturally-occurring broken fibres was counted directly in 100 microscopic fields of each yarn; for Umri Bani the mean value was obtained from counts of 1,000 microscopic fields for each yarn; and for 1027 A.L.F., Mollisoni and Nandyal 14, the naturally-occurring broken fibres were counted in the two pieces of each broken specimen for six fields beyond the region of breakage, so that for these cottons the mean value for each yarn was obtained from 2,160 observations. The diameter of the microscopical field of vision in all these experiments was 2·2 mm. As explained on page T577, however, it was found that the results thus obtained did not always tally with the values calculated from a knowledge of the number of fibres in the cross-section and the fibre-length, so that the direct counts were finally used only for ascertaining the relative proportions of broken-fibre ends, cut-fibre ends, and apical ends. The number of broken-fibre ends, counted in the affected length of the two halves of a broken test-specimen, includes both the number of hairs broken in the test and those naturally occurring in that length. Thus by subtracting the number of naturally-occurring broken ends from this total we obtain the number of broken ends due to the breaking of the yarn; and since each fibre yields two broken ends when it breaks, by halving this number of broken ends we obtain the number of fibres actually broken in the test. A count is also made of the number of fibres in the cross-section of each test piece. From the number of fibres broken in the test and the number present in the cross-section, it is a simple matter to calculate the percentage number of fibres broken in the test. The following details show the application of the original unmodified method in the case of a specimen of 40's yarn of Nandyal 14—

(1) Initial twist, 60 turns per 3 inches.

(2) Twist removed, 10 turns per 3 inches.

(3) Twist remaining in specimens, 50 turns per 3-inch length.

(4) Length affected in break, 13 mm., or 6 fields.

(5) Breaking load of yarn, 5·9 oz.

(6) Number of broken-fibre ends in 6 fields, 49 in one half and 45 in other half=94 in all.
(7) Average number of naturally-occurring broken-fibre ends in one field, 7.
(8) Average number of naturally-occurring broken-fibre ends in 6 fields, $6 \times 7 = 42$.
(9) Number of broken-fibre ends due to yarn breakage, $94-42=52$.
(10) Number of fibres broken during yarn breakage, $\frac{52}{2}=26$.
(11) Mean number of fibres at a cross-section, 64.
(12) Percentage number of fibres broken in yarn-breakage, 41.
(13) Weight of test-specimen, 1·1 mg.
(14) Counts of yarn, 40·9.

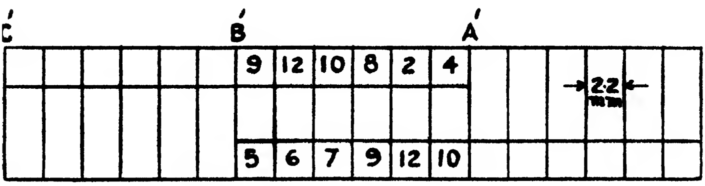

FIG. 2

A schematic diagram of the number of broken-fibre ends counted in the several microscopical fields is given in Fig. 2. Each rectangle represents the microscope field of 2·2 mm. diameter. A B represents the length affected in a break and BC the length beyond breakage over which the naturally-occurring broken-fibre ends were counted in Surat 1027 A.L.F., Mollisoni, and Nandyal 14.

Yarn-diameter—The diameters of the yarns at different degrees of twist were measured by means of an eye-piece micrometer in a low power microscope. The microscope tube was carried in a stand placed alongside the twist machine. A specimen of yarn 6 inches long was marked with black ink at ten places half an inch apart, and the diameter measured at these places at the following four degrees of twist—5, 10, 20, and 30 turns per inch. Ten specimens of each yarn, having a total length of 60 inches, were used for the determination of the diameter in each case.

Distribution of twist in thick and thin places—A few experiments were made to determine the distribution of twist in thick and thin portions of 3-inch lengths of a 40's mock-grandrelle yarn of 289 F. These specimens were specially selected as having a large variation in the 3-inch length; the specimen was placed in the jaws of the testing machine so that the lengths of the thick and thin places were approximately equal, viz., $1\frac{1}{2}$ inch. The average diameter of each half of the yarn was measured, and also its weight, and the number of fibres in its cross-section. Measurements of the distribution of twist were made in two series; in the first series, the thin piece of the yarn was inserted in the revolving jaw and the thick piece in the fixed jaw; while in the second series, the thick piece was inserted in the revolving jaw and the thin piece in the fixed jaw. Ten specimens were measured in each series. Measurements of the distribution of twist were made on each

specimen as the twist was gradually reduced 10 turns at a time, from 70 to 10 turns in the 3-inch length, and thereafter as the twist was similarly increased from 10 turns to 70 turns.

III—DISCUSSION OF RESULTS

(1) The effects of twists and tension on the diameter of cotton yarn

Table II shows the results obtained for the measurements of diameter of the different counts of various cottons at different degrees of twist.

Table II
The effect of twist on the diameters of yarns

Cotton	Counts	Diameter (mm.) 5 turns per inch	10 turns per inch	20 turns per inch	30 turns per inch
1027 A.L.F.	20·0	0·324	0·270	0·200	0·184
P.A. 4F	18·1	0·386	0·297	0·214	0·195
P.A. 289F	19·5	0·381	0·304	0·219	0·199
Umri Bani	20·4	0·339	0·262	0·197	0·179
N. 14	20·5	0·339	0·267	0·194	0·174
Mean	19·7	0·354	0·280	0·205	0·186
1027 A L.F.	31·2	0·232	0·202	0·157	0·145
P.A. 4F	29·5	0·245	0·214	0·162	0·154
P.A. 289F	28·4	0·280	0·235	0·184	0·167
Umri Bani	29·2	0·252	0·212	0·162	0·149
N. 14	25·9	0·255	0·215	0·159	0·148
Mean	28·8	0·253	0·215	0·165	0·152
1027 A.L.F.	38·9	0·219	0·187	0·137	0·127
P.A. 4F	36·5	0·210	0·179	0·149	0·135
P.A. 289F	40·2	0·214	0·179	0·142	0·132
Umri Bani	40·5	0·195	0·169	0·134	0·125
N. 14	39·2	0·206	0·189	0·148	0·136
Mean	39·1	0·209	0·180	0·142	0·131
Mollisoni	10·5	0·411	0·345	0·287	0·265

These results are plotted in Fig. 3, which shows the mean diameter at different degrees of twist for each count. It will be observed that the diameter is comparatively large at low twist, and is rapidly reduced by the insertion of twist until a point is reached when the insertion of further twist has comparatively little effect upon the diameter. The three curves for 20's, 30's, and 40's counts can be represented fairly accurately by the equation

$$d=0{\cdot}066+\frac{7}{\sqrt{n}.\sqrt[4]{c^3}(1+0{\cdot}008c)} \quad \text{.......................}(1)$$

In this formula d=diameter of yarn, in millimetres.

n=number of turns of twist per inch.

c=counts of yarn.

This formula can apply only over a restricted range of counts because the value of d, when either c or n is large, obviously approaches the limit 0·066; nevertheless, it may apply for an extensive practical range outside the 20–40's range from which it has been developed.

An alternative formula which fits these results quite closely between the range of twist-constants 3 to 7 is—

$$d=\frac{1\cdot 9}{\sqrt{c}.\sqrt[4]{n}} \qquad \text{...(2)}$$

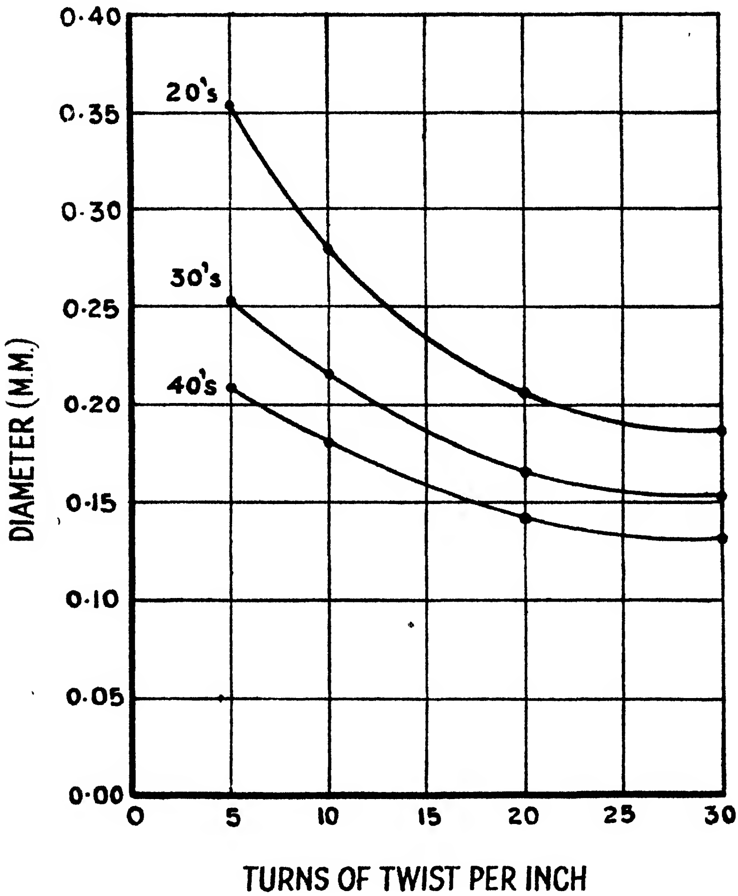

FIG. 3 Mean values of diameters of cotton yarns at various twists.

This formula may be compared with that which expresses the rule often given for the determination of the diameter of a cotton yarn, viz., the reciprocal of the diameter in inches equals the square root of the number of yards per lb. less 10 per cent. This rule may be otherwise expressed, viz., that the reciprocal of the diameter *in millimetres* is equal to the square root of the count, or $d=\frac{1}{\sqrt{c}}$. It will be observed that the second new formula developed above differs from that expressed in this rule by making due allowance for the effect of the twist; there is no difference between them

so long as $\sqrt[4]{n}=1\cdot9$, or $n=13\cdot0$ turns per inch. But this new formula itself breaks down for the 20's to 40's counts in the region of very low twist represented by the twist-constants 1 to 3. The closeness with which the new formulæ apply will be evident from Table III, showing the observed mean values of the diameter for different counts and twists, together with the calculated values derived from the two new formulæ.

Table III

Diameters of Yarns (μ)* for various cottons and twists

Counts	5 turns per inch			10 turns per inch			20 turns per inch			30 turns per inch		
	Observed	Calculated		Observed	Calculated		Observed	Calculated		Observed	Calculated	
		(1)	(2)		(1)	(2)		(1)	(2)		(1)	(2)
19·7	354	354	286	280	270	240	205	210	203	186	184	183
28·8	253	270	236	215	210	201	165	168	168	152	149	152
39·1	209	218	203	180	174	171	142	142	144	131	128	130

* 1μ=one-thousandth of a millimetre.

It is noteworthy that both the new formulæ apply to a range of counts and of twists, and yet contain no arbitrary constants. At the same time, reference to the individual values of the yarn-diameters of the different cottons appears to indicate that there are specific differences between different cottons, thus the yarn-diameter of Nandyal 14 in 20's and 30's counts is invariably less than that of 289F; however, the fact that in 40's counts the yarn-diameter of Nandyal 14 is greater than that of 289F in three cases out of four, tends to show that the aforementioned differences are probably nothing more than errors of sampling. Similar anomalies appear when the yarns of any other pair of cottons are compared.

As the yarn-diameter may be expected to decrease with increase of tension a few experiments were made to determine the degree of any such effect. The mean results for 10 tests each are shown in Table IV.

Table IV

The effect of tension on yarn diameter (mm.)

Cotton	Counts	Turns per inch	Tension 6 g	56 g	106 g
N 14	29·3	30	0·151	0·149	0·145
	27·0	20	0·159	0·158	0·156
289F	26·6	30	0·163	0·161	0·160

From this table it is clear that the effect of tension is very small compared with the effect of twist.

(ii) Distribution of twist in thick and thin places

The mean results obtained for the 40's yarn of 289F, in both the series A and series B experiments, are shown in Table V and graphically in Fig. 4.

As is to be expected, in both series the thin place has decidedly more twist than the thick place at each degree of twist, the actual difference being greater as the total twist is greater. It is interesting to note, however, that

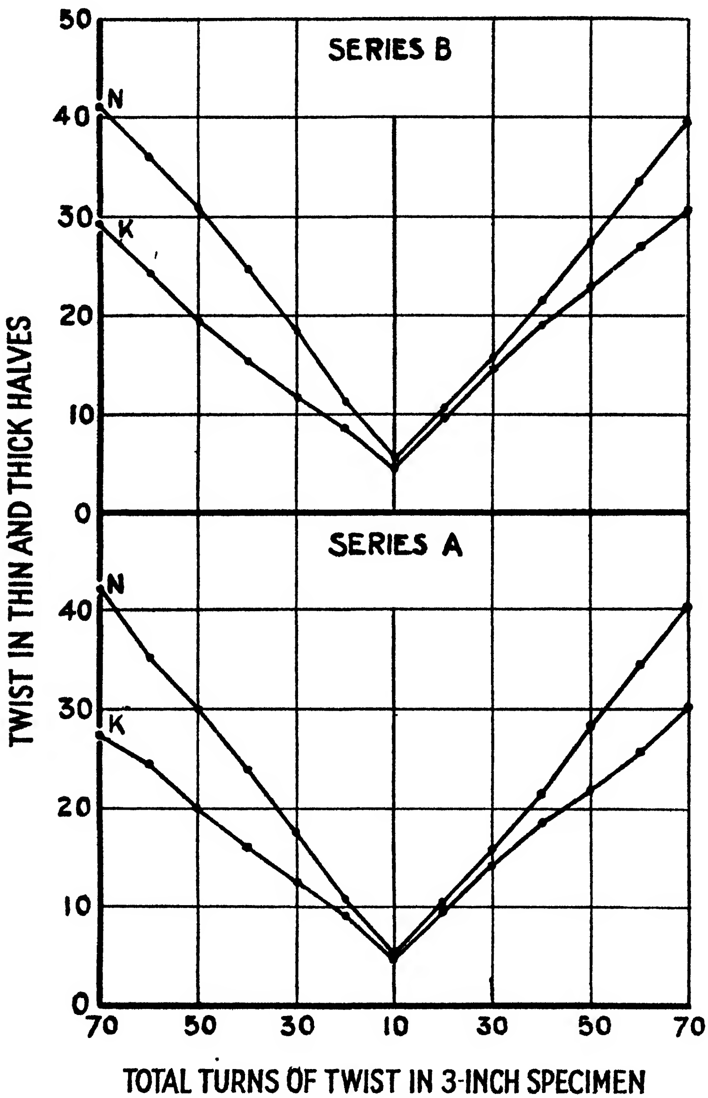

FIG. 4

The distribution of twist between thick (K) and thin (N) halves of a 3-inch specimen.

the difference between the twists of the thick and thin halves at any given twist is less during re-twisting than during un-twisting; this feature also is common both to the series A and the series B tests.

Table V

Distribution of twist in thick and thin places

Total twist (turns per 3 in.)	Series A: No. of turns of twist in — Thick half	Series A: No. of turns of twist in — Thin half	Series A: Percentage of twist in — Thick half	Series A: Percentage of twist in — Thin half	Series B: No. of turns of twist in — Thick half	Series B: No. of turns of twist in — Thin half	Series B: Percentage of twist in — Thick half	Series B: Percentage of twist in — Thin half	Mean percentage of twist (Series A & B) in — Thick half	Mean percentage of twist (Series A & B) in — Thin half
70	28	42	40	60	29	41	41	59	40	60
60	25	35	42	58	24	36	40	60	41	59
50	20	30	40	60	19	31	38	62	39	61
40	16	24	40	60	15	25	38	62	39	61
30	12	18	40	60	12	18	40	60	40	60
20	9	11	45	55	9	11	45	55	45	55
10	5	5	50	50	4	6	40	60	45	55
20	10	10	50	50	10	10	50	50	50	50
30	14	16	47	53	14	16	47	53	47	53
40	19	21	48	52	19	21	48	52	48	52
50	22	28	44	56	23	27	46	54	45	55
60	26	34	43	57	27	33	45	55	44	56
70	30	40	43	57	30	40	43	57	43	57

From Table V it is clear that in the reduction of the twist in the yarn from 70 to 10 turns, the average proportions of twists in the thick and thin halves remain practically the same at 41 and 59 per cent. respectively; now the numbers of fibres was 61 and 39 per cent. in the thick and thin halves respectively. It can therefore be taken that the distribution of the twist over a large range is such that the number of turns of twist in any part of a given yarn is approximately inversely proportional to the number of fibres in that part.

The average initial diameter, weight, and number of fibres in the cross-section, were also determined for the thick and thin pieces of each yarn, The ratios of their values for the thin pieces to those for the thick pieces are shown below.

Series	Diameter	Yarn-weight per cm.	No. of Fibres in cross-section
Series A	0·66	0·61	0·60
Series B	0·60	0·61	0·65

It is remarkable that the ratio of the diameters is practically the same as that of the yarn-weights per unit length and of the numbers of fibres in the cross-section, the average value of all the ratios being 0·62. That the ratio is the same for the yarn-weight per centimetre as for the number of fibres in the cross-section is just what would be expected if there were no undue concentration of either fine or coarse fibres in either the thin or thick places. But it is more surprising that the ratio should be the same for the diameters. The equality must be regarded as a consequence of the unequal distribution of twist in the thick and thin places, the greater proportion of twist in the thin place causing its fibres to be more concentrated, i.e., brought

much closer together, than those in the thick place. Were the concentration of fibres to be the same in the thick and thin places one would expect the ratio of the diameters to be the square root of the ratio of the numbers of fibres in the cross-section, i.e., 0·79 instead of 0·63.

(iii) The relations between twist, yarn-strength, fibre-strength, and percentage of broken fibres

Twist and yarn-strength—The results showing the relation between the twist and yarn-strength are given in Table VI for each count of each cotton.

Table VI

Yarn-strengths at different twists for various counts

Cotton 1926–27		Turns of twist per 3 inches								
		90	80	70	60	50	40	30	20	10
1027 A.L.F. ...	Counts (20's)	20·6	20·5	20·2	21·1	21·1	22·8	20·3	21·3	20·7
	Strength (oz)	19·3	19·9	17·9	16·0	13·2	9·2	4·5	0·7	0·34
	Counts (30's)	28·1	33·6	32·8	29·3	29·6	29·7	31·6	30·8	30·3
	Strength (oz)	13·0	12·0	11·6	10·1	8·7	5·8	2·8	0·5	0·36
	Counts (40's)	35·0	40·3	38·3	40·0	39·8	30·7	41·4	39·6	40·3
	Strength (oz)	9·7	8·6	8·4	7·7	6·4	4·7	1·3	0·62	0·22
P.A. 4F ...	Counts (20's)	19·9	21·1	20·3	20·5	19·4	18·6	19·2	20·4	19·1
	Strength (oz)	15·8	14·7	15·1	12·5	11·3	8·8	3·4	0·5	0·20
	Counts (30's)	25·9	26·0	28·0	27·6	28·0	28·0	28·3	30·8	27·8
	Strength (oz)	11·9	11·7	10·6	9·8	8·0	5·4	2·4	0·3	0·15
	Counts (40's)	33·6	35·2	37·3	37·6	37·5	35·9	33·6	42·8	36·7
	Strength (oz.)	8·8	9·2	7·8	7·1	5·1	2·3	0·4	0·2	0·20
P.A. 289F ...	Counts (20's)	21·3	20·3	20·3	20·5	20·8	20·2	20·4	18·3	20·5
	Strength (oz.)	21·1	18·5	20·0	15·1	15·8	12·5	8·0	0·97	0·25
	Counts (30's)	28·8	30·4	32·9	29·3	27·8	29·6	26·8	30·2	31·9
	Strength (oz.)	14·2	14·4	13·3	12·1	10·4	7·1	4·0	0·8	0·20
	Counts (40's)	38·1	34·1	36·4	38·8	39·3	38·0	37·3	38·8	39·9
	Strength (oz.)	11·2	10·8	10·4	9·5	8·5	6·9	2·8	0·7	0·30
Umri Bani	Counts (20's)	19·2	21·9	21·7	19·7	19·6	21·3	22·8	20·3	21·5
	Strength (oz)	19·3	18·2	18·1	15·3	13·9	8·4	2·2	0·3	0·25
	Counts (30's)	31·0	31·0	29·7	29·6	30·3	28·5	31·6	28·9	31·2
	Strength (oz)	12·9	12·5	12·1	11·0	7·5	4·8	1·3	0·4	0·25
	Counts (40's)	39·8	38·8	37·7	45·2	39·7	36·0	35·7	37·5	37·5
	Strength (oz.)	10·7	9·4	8·9	8·2	6·7	3·9	1·2	0·5	0·24
N 14	Counts (20's)	21·6	20·3	21·4	21·1	20·8	20·6	21·2	20·6	20·2
	Strength (oz)	20·0	19·1	16·7	15·9	13·6	8·9	3·4	0·6	0·20
	Counts (30's)	27·3	28·7	29·2	30·0	29·6	31·1	29·2	30·5	30·5
	Strength (oz.)	14·7	14·1	12·9	11·1	9·9	5·4	1·7	0·3	0·20
	Counts (40's)	40·0	40·7	40·7	40·9	40·3	41·4	36·6	37·5	37·8
	Strength (oz.)	8·9	8·2	7·3	7·0	6·2	3·4	1·0	0·4	0·20
Mollisoni ...	Counts (10's)	11·7	11·0	11·1	11·6	12·2	10·8	10·5	9·9	10·3
	Strength (oz.)	20·7	21·6	16·2	17·7	14·6	11·3	4·2	0·96	0·29

These results differ somewhat from those published by other workers. In the first place, the experiments have been extended to much lower degrees of twist than is customary; and in the second place, the curves as a general rule do not show any well-marked maximum value of strength for any degree

Table VIa
Yarn-strength values from "Technological Reports"

Cotton		Turns per 3 inches 50·55	65·58	80·91
1027 A.L.F.	Counts	(20)	(30)	...
	Strength (oz.)	12·3	7·8	...
P.A. 4F	Counts	20·2	29·5	...
	Strength (oz.)	10·1	6·8	...
P.A. 289F	Counts	19·9	30·0	39·0
	Strength (oz.)	14·8	9·2	6·8
Umri Bani	Counts	(20)	...	...
	Strength (oz.)	10·0	...	...
Nandyal 14	Counts	19·9	30·6	40·5
	Strength (oz.)	12·4	7·7	5·6

of twist used in these experiments. As will be seen from Table VI, the increases in strength with twist are not always regular for any particular count of a single cotton, nor do the increases for different cottons at a given count by any means follow exactly the same curve. Both types of differences persist even when due allowance is made for the departure of the actual from the nominal counts by comparing the count-strength products at different twists. as will be clear from the values given in Table VII.

The curves of Fig. 5 show the mean strength values at different twists for all the cottons in the different counts. These curves display a number of features in common: the yarn-strength increases very slowly indeed up to a twist of 20 turns per 3 inches for all counts; thereafter, there is a rapid increase of strength between 20 and 50 turns per 3 inches both for 20's and 30's counts, though the increase is less rapid for the 30's counts than for the 20's, particularly in going from 20 to 30 turns per 3 inches. For the 40's yarn the rapid increase of strength does not occur until the number of turns reaches 30 turns per 3 inches, and the most rapid increase is between 30 and 40 turns per 3 inches. It is very noteworthy that the maximum strength for different counts of yarn appears to be attained at about the same twist, viz., 90 turns per 3 inches. This corresponds to twist-constants of 7 for 20's, 5·5 for 30's and 4·5 for 40's. The results for the lower counts are quite contrary to those previously published; the divergence must in all probability be attributed to the fact that the selection of the test-specimens in these experiments was deliberately biassed, as only specimens which appeared to the eye to be of medium and uniform diameter were chosen for these tests. Had the yarn been selected indiscriminately, as in the usual method, it would of course have included a number of specially thin places which would have been overtwisted at the high twist-constants, and which would therefore have been places of special weakness; the presence of such places would have greatly depressed the average strength at the highest twist, and the maximum strength would have been attained at some lower twist, as in the experiments of other workers.

From the curves of Fig. 5 it is clear that up to some 20 turns per 3 inches the influence of twist is so small that although it causes some increase in the

Table VII

Count-strength products at different twists for various counts

Cotton 1926–27	Counts	Turns of twist per 3 inches								
		90	80	70	60	50	40	30	20	10
1027 A.L.F. ...	20's	399	400	360	336	273	207	80	15	7
	30's	364	408	396	290	270	180	96	15	11
	40's	350	360	304	320	240	185	41	24	9
Mean ...		371	389	353	315	261	191	72	18	9
P.A. 4F ...	20's	320	315	300	260	209	171	57	10	4
	30's	312	312	308	280	224	140	56	9	4
	40's	306	315	296	266	228	72	14	9	7
Mean ...		313	314	301	269	220	127	42	9	5
P.A. 289F ...	20's	441	380	400	300	326	260	160	18	5
	30's	406	420	429	348	280	210	108	24	6
	40's	418	374	360	351	351	266	111	27	12
Mean ...		421	391	396	333	319	245	126	23	8
Umri Bani ...	20's	361	396	396	300	280	168	46	6	5
	30's	403	403	360	330	240	145	32	12	8
	40's	440	351	333	360	280	144	36	19	9
Mean ...		401	383	363	330	267	152	38	12	7
N. 14	20's	440	380	357	336	294	189	63	13	4
	30's	405	406	377	330	300	155	58	9	6
	40's	360	328	287	287	240	123	37	15	8
Mean ...		402	371	340	318	278	156	53	12	6
Mollisoni ...	10's	252	242	176	216	180	121	40	10	3

clinging power of the fibres, up to this degree of twist the breakage of the yarn takes place almost entirely by fibre-slippage. The rapid ascent of the curves between 20 and 50 turns per 3 inches, whereby the yarn-strength increases 23-fold for 20's counts, 18-fold for 30's counts, and 14-fold for 40's counts, indicates that between these degrees of twist there is a rapid extension of the zone in which the twist causes the fibres to break rather than slip. Beyond a twist of 50 turns per 3 inches, the increase in strength produced by increase of twist becomes less and less rapid, simply because the scope for its influence becomes less, and the surface fibres make a greater and greater angle with the yarn-axis. It will be apparent that within the range of twist used in the spinning of most commercial yarns, yarn-breakage takes place chiefly by fibre-fracture.

Turning now to the individual cottons we see that there is much less difference in their strength values than might have been expected. It is true that of the five better class cottons P.A. 4F invariably has the lowest maximum value in 20's and 30's counts, and in 40's counts shares this distinction with Nandyal 14. But Umri Bani, which in 1926–27 resembled P.A. 4F

in being suitable for counts up to 24's, has only slightly less maximum strength values than P.A. 289F in 20's and 30's counts, and an equal value in 40's counts, yet the P.A. 289F is suitable for 40's counts as against the 24's of the Umri Bani.

It is certainly surprising that the maximum strength values of the individual cottons in no way reflect the highest suitable warp counts. This

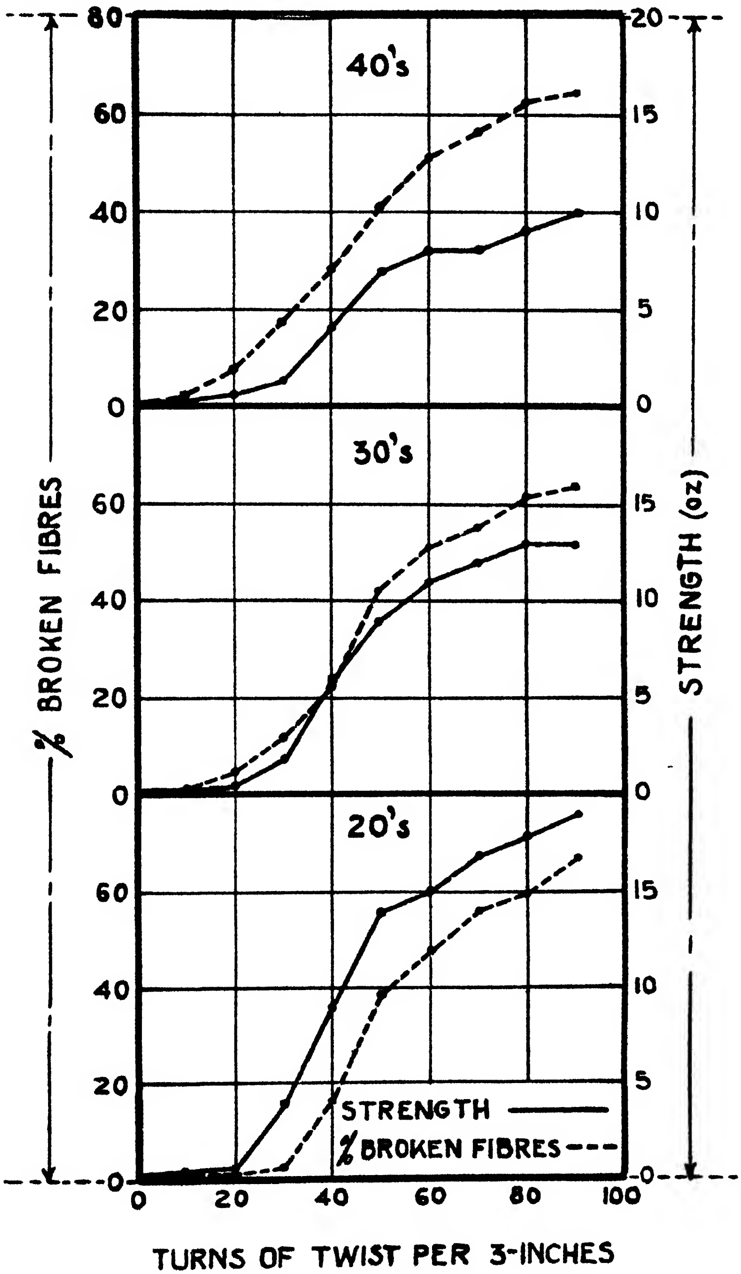

Fig. 5

The relation between twist, yarn-strength, and percentage of broken fibres.

shows that at the highest twists the strength of the yarn is but slightly dependent upon the variety of cotton; the same conclusion has been arrived at by Gurney,[8] who states that different cottons spun with the twist-constant 10 all yielded the same strength value for the yarn of a given count. But this conclusion, on the evidence of the present tests, must not be pushed too far, for the strength of Mollisoni in 12's counts spun with 90 turns per 3 inches is actually much the same as that of most of the better-class cottons in 20's counts with the same twist. However, the results for the five better-class cottons must certainly be regarded as very significant; and the deduction must be drawn that some of the fibre-properties are important not so much for the strength they confer at the place of breaking as for the fact that they determine what the structure of the yarn shall be, and govern the frequency and degree of thick and thin places in the yarn. Thus although two cottons may give the same strength when their fibres are evenly arranged so as to give a uniform yarn with uniform twist, yet if in the spinning process the fibre-properties of one are more favourable to the production of a uniform yarn than the fibre-properties of the other, then the first cotton will be capable of being spun to a higher standard counts.

Table VIII

Percentage of broken fibres at different twists for various counts

Counts	Cotton	Turns of twist per 3 inches								
		90	80	70	60	50	40	30	20	10
20's	1027 A.L.F ...	68·8	64·7	58·5	47·4	41·6	21·4	5·1	0·8	...
	P.A. 4F ...	60·4	54·1	54·3	43·2	34·0	12·6	...	...	...
	P.A. 289F ...	69·6	54·5	51·4	44·6	36·8	21·0	1·3	1·1	0·5
	Umri Bani ...	65·8	62·6	61·6	51·7	44·5	9·1	3·5	0·4	...
	Nandyal 14 ...	68·5	65·1	60·3	51·2	39·7	20·8	6·7	3·5	0·8
	Mean ...	66·6	60·2	57·2	47·6	39·3	16·9	3·3	1·16	0·26
30's	1027 A.L.F. ...	72·1	65·9	59·9	48·8	47·2	20·8	9·2	4·6	2·7
	P.A. 4F ...	50·1	49·3	45·5	35·7	24·4	16·1	5·1	1·1	...
	P.A. 289F ...	64·7	54·4	53·1	54·2	46·5	30·1	18·5	9·8	1·7
	Umri Bani ...	64·2	66·1	58·9	57·9	40·4	19·7	8·8	1·4	...
	Nandyal 14 ...	62·9	66·9	58·9	56·2	50·6	26·5	18·4	8·2	1·0
	Mean ...	62·8	60·5	55·3	50·6	41·8	22·6	12·0	5·0	1·08
40's	1027 A.L.F. ...	63·2	64·5	57·8	52·0	42·2	31·2	12·7	6·6	0·3
	P.A. 4F ...	62·1	65·9	54·8	50·1	34·0	25·4	16·1	5·5	1·3
	P.A. 289F ...	61·3	60·6	57·9	51·9	52·1	42·5	36·2	14·9	4·3
	Umri Bani ...	64·0	61·3	53·6	46·8	33·5	8·4	1·6	...	0·3
	Nandyal 14 ...	67·4	58·1	56·0	52·5	41·9	33·6	22·2	13·7	6·3
	Mean ...	63·6	62·1	56·0	50·7	40·7	28·2	17·8	8·1	2·5
10's	Mollisoni ...	55·1	48·8	36·2	27·9	7·3	...	...	...	...

Yarn-strength and percentage of broken fibres—We come now to the consideration of the proportion of fibre-fracture in relation to the twist and

yarn-strength. The results for the different cottons in different counts with various degrees of twist are given in Table VIII. The mean values for all the cottons at each count and degree of twist are also included in this table; these mean values have been plotted together with the corresponding strength values in Fig. 5, from which it is at once evident that there is a close relation between the percentage of fibre-fracture and the yarn-strength; the same is clear from the correlation-coefficients for the mean strengths of different counts and the corresponding mean values of the percentage of fibre-fracture; these correlation-coefficients are as follows—

20's : 0·94;
30's : 0·97;
40's : 0·99.

Although these correlation-coefficients have each been determined from 9 pairs of values only, they are all highly significant, as there is only one chance in 100 that random sampling alone will give a correlation-coefficient even as high as 0·80.[9]

From the counts of the broken fibres it appeared that when due allowance was made for the number of naturally-occurring broken-fibre ends the degree of fibre-breakage at the low twist was far greater than was expected; it amounted to some 20% for all three counts, 20's, 30's, and 40's, even at so low a twist as 10 turns per 3 inches. Such a high value must apparently be attributed to some systematic error in the counting of the naturally-occurring broken ends. The only alternative explanation is that this breakage is real; but the yarn-strength at 10 turns per 3 inches was approximately a quarter of an ounce, or 7 grams, for either 20's, 30's, or 40's, so that in 20's yarn, containing about 150 fibres in the cross-section the average load per fibre was no more than 0·05 gram; it is possible to conceive of fibre-slippage occurring under these conditions, owing to the smallness of the compressive forces at this low twist, but it is impossible to believe that 20% of the fibres broke under such a small load, for from an analysis of frequency-distributions of fibre-strength we know that only about 4% of the fibres break when the individual load is as great as 1 gram, or 20 times as high as the actual load per fibre when the yarn broke at this low twist. Hence it was concluded that some error had been committed in the counting of the naturally-occurring broken fibre ends, and this possibility was therefore examined further. Fortunately, when the broken-fibre ends were counted the numbers of cut fibre ends and apical ends were also noted, as described on page T565. Now from a knowledge of the average number of fibres in the cross-section and the average length of a fibre, we were able to calculate in a simple manner the number of naturally-occurring fibre-ends in a given length of yarn; for if L = the length of the yarn, l = the average fibre-length, and n = the average number of fibres in the cross-section, then the average number of fibre-ends per length L of yarn $= \frac{2nL}{l}$. The average values obtained for fibre-length, fibre-weight per inch, and number of fibres in the cross-section for different counts of the various cottons are given in Table IX.

Table IX

Number of naturally-occurring fibre-ends per inch of yarn

Cotton	Fibre-length (inch)	Fibre-weight per inch (10^{-7} oz.)	Naturally-occurring fibre-ends per inch 10's	20's	30's	40's
1027 A.L.F.	0·97	0·241	...	216	148	138
P.A. 4F	0·78	0·170	...	402	286	218
P.A. 289F	0·97	0·134	...	400	274	214
Umri Bani	0·81	0·187	...	327	236	184
Nandyal 14	0·93	0·198	...	274	198	146
Mollisoni	0·68	0·307	470	...	...	...

The calculation of the number of fibre-ends was duly made for each yarn, and in each case it was found that the value obtained was considerably greater than the total of broken, cut, and apical ends obtained by direct counting; and as the chances of error in the indirect method are really much less than in the direct counting method, the figures for the number of broken fibres have been adjusted accordingly, on the assumptions that the correct total number of naturally-occurring fibre-ends is the number given by the indirect method, and that the relative proportions of broken, cut, and apical ends were the same as obtained by direct counting.

As previously remarked, the curves showing the percentage of fibre-fracture at different degrees of twist closely resemble those for yarn-strength under similar conditions. It is noteworthy, however, that although the percentage of broken fibres is practically the same at the highest twist for the three counts, 20's, 30's, and 40's, yet at 40 turns per 3 inches and at lower twists the curves diverge—the finer cotton having a higher percentage of broken fibres at a given twist. Moreover, not only the percentage but also the actual number of fibres broken at these low twists is greater for the 40's and 30's yarns than it is for the 20's at the 30, 20, and 10 turns per 3 inches. This is certainly a surprising result; it may be a consequence of errors in sampling or in counting, but from the form of the curves this would hardly appear to be the case. At the same time, the curves showing the percentage of fibre-fracture at different degrees of twist are distinctly irregular for the individual cottons in particular counts; and further, for any one count and at any one degree of twist, there are notable differences in the percentage of broken fibres for the different cottons. These divergencies are particularly marked in the 30's and 40's counts, and it is conceivable therefore that they are really responsible for the curious feature that the number of broken fibres in the 40's yarn, at low twist actually exceeds the number of broken fibres in the 20's yarn at the same twist.

As previously pointed out, if we compare the individual cottons we see that most of them give very similar strength results in a given count for a given degree of twist, except at the very low twist. The chief exception is Punjab-American 4F, which gives below the average strength and below the average percentage of broken fibres in 20's and 30's counts in all twists except the 40 turns per 3 inches in 20's counts, for which its strength is the same as the average though the percentage of fibre-fracture is below the average. At this particular twist and count Umri Bani also gives a very low figure for the percentage of broken fibres, though this is probably due to the correction for the number of naturally-occurring broken ends being

abnormally high in this case. In the 40's yarn the percentage of fibre-fracture at a given low twist (50 turns per 3 inches and less) varies very much for the different cottons; both 4F and Umri Bani give low values, those for the latter being exceptionally low at 40 turns per 3 inches and less; these low values are not due to large corrections, but to the fact that the actual numbers of broken fibres at the places of break were themselves abnormally low. Though, in view of the experimental difficulties in this work, it is perhaps undesirable to lay too much stress upon these exceptional cases; nevertheless, it is probably not without significance that both Punjab-American 4F and Umri Bani are cottons which are suitable for standard warp counts of 24's only, whereas 1027 A.L.F., 289F, and N. 14, are respectively suitable for 32's, 40's, and 34's.

At 90 turns per 3 inches the average percentage of broken fibres for all cottons is much the same for each count, being 67, 63, and 64 per cent. for 20's, 30's, and 40's respectively. It is possible that the actual percentages are somewhat higher than these figures indicate, because if any broken ends should have been overlooked in the counting these figures would be too low.

Percentage of fibre-strength utilised—Table X shows the percentage of strength "utilised"; each figure in this table has been calculated from the known single thread strength in relation to the product of the fibre-strength and the number of fibres in the cross-section. The values for the fibre-strengths have been taken from "Technological reports on standard Indian cottons",[6] and the number of fibres in the cross-section has in each case been calculated from the fibre-weight per inch.

It will be observed that at the high twists the percentage of fibre-strength utilised reaches a very high figure. Indeed, in the case of Punjab-American 289F in 20's yarn with 90 turns per inch, the percentage of fibre-strength utilised actually amounts to 103%; and as this is an average of 20 values it is clear that for some specimens the percentage of strength utilised must considerably exceed this value; in actual fact, for 15 of the 20 specimens the percentage of strength utilised exceeds 100%, the six highest values being 119, 115, 115, 112, 112, 111 per cent. Although in no other case did the *average* value of the percentage of strength utilised exceed 100%, yet it did so for quite a number of individual specimens, as indicated in the following list, in which the number before each bracket represents the number of such specimens out of 20 specimens tested at the particular twist per 3 inches represented by the number in brackets itself—

P.A. 289F :	20's:	15(90), 3(80), 7(70), 1(60).
	30's:	6(90), 9(80), 12(70), 1(60).
	40's:	8(90), 2(80), 4(70), 2(60).
P.A. 4F :	20's:	3(90), 1(70).
	40's:	2(80).
1027 A.L.F. :	20's:	2(90), 5(80).
	30's:	4(80), 1(70).
	40's:	1(90).

These values are much higher of course than have been generally recorded in the past; thus the values given in Part II of this series of papers[10] give an average value of about 50% for the percentage of fibre-strength "utilised" in the single thread strength tests on standard Indian cottons, while Bowman's and Monie's results[11] indicated that less than 12% of the fibre-

Table X

Percentage of fibre-strength "utilised" at different twists

Cotton	Turns of twist per 3 in.	20's				30's				40's			
		No. of fibres	Strength			No. of fibres	Strength			No. of fibres	Strength		
			Calculated	Observed	% utilised		Calculated	Observed	% utilised		Calculated	Observed	% utilised
1027 A.L.F.	90	126	21·2	19·3	91	91	15·3	13·0	85	74	12·5	11·2	90
	80	124	20·9	19·9	95	77	13·0	12·0	92	62	10·9	8·6	79
	70	128	21·6	17·9	83	75	12·6	11·6	92	66	11·1	8·4	76
	60	122	20·6	16·0	78	88	14·8	10·1	68	63	11·2	7·7	69
	50	121	20·4	13·2	65	89	15·0	8·7	58	65	11·9	6·4	54
	40	114	19·2	9·2	48	87	14·7	5·8	39	70	11·8	4·7	40
	30	124	20·9	4·5	21·5	80	13·5	2·8	21	64	11·6	1·3	11·1
	20	121	20·4	0·7	3·3	83	14·0	0·5	3·6	66	11·1	0·6	5·3
	10	122	20·6	0·3	1·5	85	14·3	0·4	2·8	66	11·1	0·2	1·8
P.A. 4F ..	90	147	19·7	16·0	81	110	14·7	11·9	82	87	11·7	9·0	77
	80	139	18·6	15·0	81	109	14·6	11·7	80	82	11·0	9·0	82
	70	144	19·3	15·0	78	102	13·7	10·6	77	75	10·0	8·0	80
	60	142	19·0	12·5	66	103	13·8	9·8	71	77	10·3	7·0	68
	50	152	20·4	11·3	55	102	13·7	8·0	59	78	10·5	6·0	57
	40	155	20·4	8·8	43	102	13·7	5·4	39	82	11·0	2·0	18
	30	152	20·4	3·3	16	101	13·5	2·4	18	88	11·8	0·4	3·4
	20	143	19·2	0·5	2·6	93	12·5	0·3	2·4	67	9·0	0·2	2·2
	10	151	20·2	0·2	0·9	102	13·7	0·15	1·1	79	11·2	0·2	1·8
P.A. 289F ...	90	185	20·5	21·1	103	142	15·8	14·2	90	105	11·7	11·2	99
	80	200	22·2	18·5	83	135	15·0	14·4	96	117	13·0	10·8	83
	70	201	22·3	20·0	90	122	13·5	13·2	98	107	11·9	10·4	87
	60	199	22·1	15·0	68	139	15·4	12·1	79	102	11·3	9·5	84
	50	199	22·1	16·0	73	148	16·4	10·4	64	101	11·2	8·5	76
	40	202	22·4	13·0	58	138	15·3	7·1	46	104	11·5	6·9	60
	30	202	22·4	8·0	36	153	17·0	4·0	24	106	11·8	2·8	24
	20	220	24·4	0·92	4	137	15·2	0·9	6	102	11·3	0·7	6
	10	197	21·9	0·25	1·7	128	14·2	0·25	1·8	99	11·0	0·3	2·7
Umri Bani..	90	154	28·8	19·3	67	95	17·8	12·9	73	73	13·6	10·7	79
	80	136	25·4	18·2	72	95	17·8	12·5	70	75	14·0	9·4	67
	70	134	25·0	18·1	72	98	18·3	12·1	66	79	14·8	8·9	60
	60	148	27·7	15·3	55	98	18·3	11·0	60	65	12·1	8·2	68
	50	150	28·0	14·0	50	96	17·9	7·5	42	75	14·0	6·7	48
	40	137	25·6	8·4	33	101	18·9	4·8	25·4	83	15·5	3·9	25
	30	129	24·1	2·2	9·2	92	17·2	1·3	7·6	84	15·7	1·2	7·7
	20	144	26·9	0·35	1·3	101	18·9	0·4	2·1	79	14·8	0·5	3·4
	10	137	25·6	0·25	0·98	94	17·6	0·25	1·4	79	14·8	0·2	1·3
N. 14 ..	90	151	34·4	20·0	58	124	28·2	14·7	52	86	19·6	8·9	45
	80	162	36·9	19·0	52	119	27·1	14·1	52	84	19·2	8·2	42
	70	156	35·5	16·7	47	113	25·8	12·9	50	82	18·7	7·3	39
	60	154	35·1	15·9	45	114	26·0	11·1	43	81	18·5	7·0	38
	50	162	36·9	13·6	38	112	25·5	9·9	39	82	18·7	6·2	37
	40	159	36·2	8·9	24·6	106	24·2	5·5	23	80	18·2	3·4	18·7
	30	158	36·0	3·4	9·4	115	26·2	1·7	6·5	92	21·0	1·0	4·8
	20	163	37·2	0·6	1·6	110	25·1	0·3	1·2	90	20·5	0·4	1·9
	10	166	37·9	0·2	0·5	110	25·1	0·2	0·8	88	20·1	0·2	1·0
Mollisoni 10's	90	144	24·2	20·7	85								
	80	153	25·8	21·6	84								
	70	154	26·0	16·2	62								
	60	147	24·8	17·7	72								
	50	141	23·8	14·6	61								
	40	159	26·8	11·3	42								
	30	165	27·8	4·2	15								
	20	173	29·1	0·96	3·3								
	10	166	28·0	0·29	1·2								

strength was "utilised" in their lea-strength tests; there is but little doubt that the present high values are a consequence of the deliberately biassed selection of the specimens of yarn used in the testing, so that the abnormally thick and thin places were omitted. In the ordinary testing the counts of the places which break are doubtless much finer than the average count of the whole yarn, so that the yarn-strength is actually that of a much finer count than the nominal count of the yarn being tested. That this is the correct explanation is borne out by the actual values for yarn-strength obtained in these tests; the single thread strengths of these cottons as reported in "Technological reports on standard Indian cottons"[7] are shown in Table VIa, following the results obtained in the present tests; it will be seen that for corresponding twist higher values have in every case been recorded in the present tests; moreover, for 20's counts, where all the cottons are being spun well within their spinning capacity so that the yarn produced is much more regular than in the higher counts, the divergencies between the strength results are much less than they are for the 30's and 40's counts. Some part of the excess of strength recorded in the present tests must be ascribed to the use of double roving in the spinning of the mock grandrelle yarns; the remainder is due to the biassed selection of the test specimens.

The question may be asked: How is it possible for the fibre-strength "utilised" in the yarn to exceed 100 per cent.[6] The answer is that the possibility arises from the fact that the fibre-strength is merely the strength of the weakest part of the fibre, and that, as pointed out in Part II,[12] the doubling together of many fibres to form a yarn makes it possible for the weakest place of a fibre to be supported by the stronger place of a contiguous fibre; and when it is remembered that other parts of the fibre, as pointed out in an earlier paper,[13] may be three or four times as strong as the weakest place, it is easy to see how the doubling effect under abnormal conditions may cause the percentage of "fibre-strength utilised" to exceed 100 per cent. The further discussion of this point is deferred to Part VI, dealing with the effects of non-uniformity of fibre-properties.

CONCLUSIONS

The following conclusions are drawn from these experiments.

(1) The diameter of a cotton yarn of a given twist per inch (n) and count (c) falling within the 20's–40's range can be obtained by substituting the values for the counts and twists in one of two formulæ, neither of which contains any arbitrary constants. The simpler formula, that the diameter in millimetres equals $1{\cdot}9/\sqrt{c}\,\sqrt[4]{n}$., applies over the practical range of twists, but not at low twists.

(2) A cotton-yarn suffers only a slight change in diameter when it is placed under tension.

(3) The distribution of twist in a yarn of varying diameter is such that the number of turns of twists in any part of the yarn is approximately inversely proportional to the number of fibres in that part; as a consequence of this unequal distribution of twist, the diameter of the yarn at any given cross-section is directly proportional to the number of fibres at that cross-section.

(4) When only uniform specimens of yarn are tested for strength, the strength of the single yarn increases with the twist in 10's to 40's yarn until 30 turns per inch have been inserted. The most rapid increase for 20's and

30's yarn is between 7 and 17 turns per inch; for 40's yarn the most rapid increase of strength is between 10 and 13 turns per inch. The influence of twist is so small at low twists that up to 7 turns per inch the breakage of the yarn takes place almost entirely by fibre-slippage.

(5) The maximum yarn-strength values of the individual cottons do not reflect their highest suitable warp counts; it is therefore concluded that some of the fibre-properties are important not so much for the strength they confer at the place of breaking as for the fact that they determine the frequency and degree of thick and thin places in the yarn.

(6) There is a very close relation between the percentage of fibre-fracture and yarn-strength, over 60% of the fibres breaking at high twist when the yarn-strength is at its highest, and very few fibres breaking at low twist when the yarn-strength is very small indeed.

(7) The values for the percentage of fibre-strength utilised, as calculated from the single thread strength in relation to the product of the fibre-strength and number of fibres in the cross-section, show that in some cases the percentage actually exceeds 100. The existence of these high values is attributed to the deliberately biassed selection of the specimens of yarn used in the testing, by virtue of which full scope is given for the display of the accession of strength possible by doubling together a number of fibres whose strength varies greatly along their length.

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TECHNOLOGICAL LABORATORY

1*st August* 1930

37—THE ESTIMATION OF STARCH ON FINISHED GOODS AND YARNS

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INTRODUCTION

In the course of a long series of experiments which were undertaken on the large scale in relation to some work on the control of the starching and blueing operation, it was found necessary to determine the amount of starch taken up by a large number of samples of linen fabric. One of the few methods available was that of estimating the loss in weight on treating the starched fabric with a desizing preparation such as Novo Fermasol. The method involves determining the moisture content accurately on a separate sample and then drying a weighed amount of the fabric after desizing. It is also necessary to determine the loss in weight on treating the unstarched fabric with the desizing solution. In cases where the unstarched fabric is not available the results are necessarily somewhat high. The time taken is considerable and involves several hours' drying and reweighing. The resulting loss in weight is usually returned as starch, but if, as is often the case, especially with huck towelling and soft finishes generally, soluble oil or soap has been used in conjunction with the starching mixture, it frequently happens that there is as much softening substance as there is starch on the fabric and as the former is removed by the desizing treatment, the method is not available for determining the starch.

A great deal of work has been done on the determinination of starch in cereals particularly from the standpoint of the fermentation industries. The majority of existing methods involve the conversion of the starch into sugar by hydrolysis with diastatic ferments or with acids. The dextrose produced is then estimated by means of Fehling's solution, or polarimetrically. Hinton and Macara[1] use a method whereby the dextrose is oxidised to gluconic acid by means of iodine. Countless modifications have been suggested for overcoming difficulties consequent on the presence of substances other than starch in the cereals and most of the reliable methods have been worked out to suit particular cases.

There is little published information available, however, as far as the determination of starch on textiles is concerned. Vorhees and Kamm[2] have worked out a method for estimating starch on paper. It is first boiled with dilute acetic acid, filtered, and the filtrate further boiled with dilute hydrochloric acid. The solution is neutralised with sodium carbonate and titrated with Fehling's solution.

The method communicated in this paper has been worked out primarily for determining the starch on finished linen goods but a few results have been included showing that it is also suitable foi estimating starch size on yarns and may also be used with cotton fabrics. The principle of the method is not new, being that of hydrolysis with dilute sulphuric acid. In estimating the dextrose produced, the excess sulphuric acid is neutralised with sodium carbonate solution, since caustic alkalies interfere with the estimation. The Fehling's solution is replaced by the solution recommended by Braidy for the determination of copper number in the method standardised by Clibbens and Geake.[3] This solution has the advantage that it contains no caustic alkali and is much more stable than Fehling's solution. With one or two additions

the solutions and the method employed are similar to those involved in the Braidy copper number determination.

GENESIS OF THE METHOD

The object aimed at was, if possible, to limit the time taken to that occupied by the normal estimation of copper number, viz. 3 hours.

The hydrolysis of starch to dextrose by means of sulphuric acid proceeds as follows—

$$\underset{\text{Starch}}{C_6H_{10}O_5} + H_2O = \underset{\text{Dextrose.}}{C_6H_{12}O_6}$$

This equation represents the final product of hydrolysis. Intermediate products are first formed, viz. soluble starch, maltose, etc., and the first set of experiments was designed to determine the minimum concentration of acid and the time required for complete hydrolysis of the starch to dextrose. For this purpose a solution of wheat starch was made up by adding 46 g. of the air dry starch, made into a paste with 250 c.c. cold water, to 2 l. of boiling water. The whole was stirred at 100° for ½ hour in an experimental starch mixing kettle, as a standard procedure. The concentration of this solution was then estimated by evaporating a weighed quantity to dryness over a steam bath and finally drying in an oven at 100° C. to constant weight.

50 g. of this solution were then carefully weighed out and made up to 1,000 c.c. with distilled water; 1 c.c. of this solution contained 0·00905 g.; 10 c.c. of the diluted starch solution were used in each experiment and varying volumes of $2N$ sulphuric acid were added, and the mixtures hydrolysed for periods of 2 and 2½ hours respectively in 175 c.c. conical flasks provided with loosely fitting glass pear stoppers and immersed in an actively boiling constant level water bath. In the first experiment the following mixture was used—

10 c.c. diluted starch solution.
35 c.c. water.
10 c.c. $2N$ sulphuric acid solution.

It was hydrolysed for 2 hours and 10 c.c. distilled water (an amount necessary for washing in the actual determination of starch on fabric) were added, followed by one drop of methyl orange solution; the solution was then nearly neutralised with $2N$ sodium carbonate solution, the methyl orange acting as indicator. The same experiment was repeated giving 2½ hours hydrolysis. The quantity of acid was then increased as follows—15 c.c., 20 c.c., 25 c.c., 30 c.c., 35 c.c., keeping the total volume constant, viz. 55 c.c. by reducing the quantity of water added. Each mixture was hydrolysed for 2 and 2½ hours respectively as before. The almost neutralised solution was then in each case heated to boiling and a boiling mixture of 95 c.c. sodium carbonate-bicarbonate solution—

Sodium carbonate (anhydrous)	129·7 g.
Sodium bicarbonate	50 g.
Water	to 1,000 c.c.

and 5 c.c. copper sulphate solution added—

Copper sulphate	100 g.
Water	to 1,000 c.c.

The whole was then heated for ½ hour by immersion in the boiling water bath.

The precipitated cuprous oxide was then filtered off through a layer of purified asbestos contained in a coarse Jena sintered glass funnel using suction. The flask was rinsed out once with a 1% sodium carbonate solution

and twice with distilled water, the liquid in each case being poured through the funnel. The funnel was then transferred to another filter flask and two successive amounts of 15 c.c. of ferric ammonium sulphate-sulphuric acid solution

Iron alum	100 g.
Concentrated sulphuric acid	140 c.c.
Water	to 1,000 c.c.

used for rinsing out the original conical flask, after which they were poured over the cuprous oxide. The first 15 c.c. were drawn through into the filter flask before adding the second amount. The cuprous oxide was thereby dissolved and reduced a corresponding amount of the ferric alum according to the equation—

$$Cu_2O + Fe_2(SO_4)_3 + H_2SO_4 = 2CuSO_4 + 2FeSO_4 + H_2O$$

The asbestos was then washed twice with $2N$ sulphuric acid solution and the filtrate titrated with $N/25$ potassium permanganate solution. The following table shows the volume of $N/25$ permanganate solution required after hydrolysing 10 c.c. of the standard starch solution with varying amounts of $2N$ sulphuric acid for periods of 2 and 2½ hours respectively. The weight of starch in each case=0·0905 g.

Table I

Volume of $2N$ H_2SO_4	Normality of acid in mixture	Time of Hydrolysis (hours)	Volume of $N/25$ permanganate (c.c.)
10 c c.	0·364 N	2	8·27
10 c.c.	0·364 N	2½	9·05
15 c.c	0·545 N	2	10·09
15 c c	0·545 N	2½	10·23
20 c.c	0·727 N	2	10·73
20 c.c	0·727 N	2½	11·32
25 c.c.	0·909 N	2	11·07
25 c.c.	0·909 N	2½	11·21
30 c c	1·091 N	2	11·03
30 c c.	1·091 N	2½	11·32
35 c c.	1·273 N	2	11·61
35 c.c.	1·273 N	2½	11·36

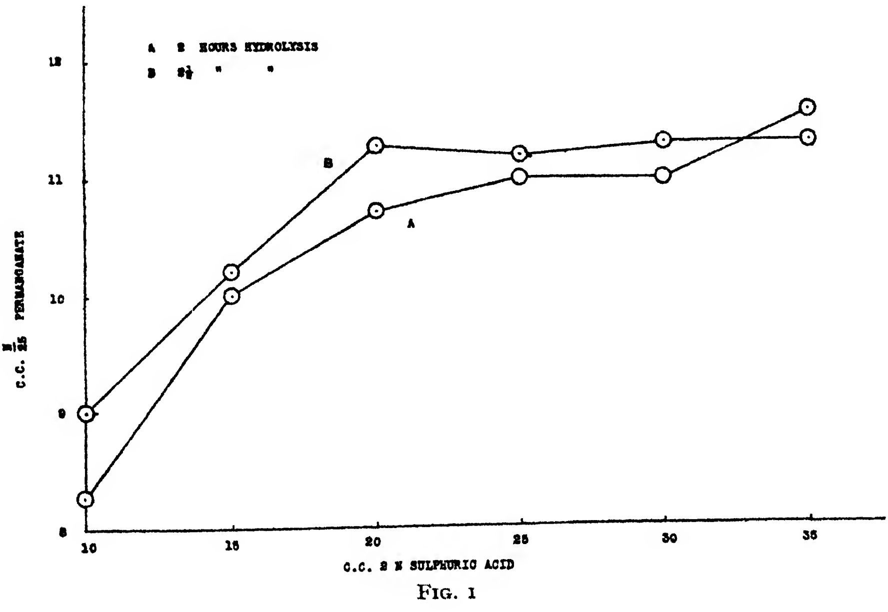

FIG. 1

The curves for these figures are shown in Fig. 1 and it was decided from them that 25 c.c. of $2N$ sulphuric acid for $2\frac{1}{2}$ hours would yield a satisfactory result.

With this mixture as standard it was then decided to conduct a series of experiments varying the time of boiling with the Braidy mixture and using a solution of pure dextrose of known concentration=0·9981 g. per l. The following mixtures were used—

(1) 5 c.c. dextrose solution (0·00499 g.).
25 c.c. water.
25 c.c. $2N$ sulphuric acid.

(2) 15 c.c. dextrose solution (0·01497 g.).
15 c.c. water.
25 c.c. $2N$ sulphuric acid.

After heating on the water bath for $2\frac{1}{2}$ hours exactly as if hydrolysis were proceeding, 10 c.c. of water were added followed by $2N$ sodium carbonate solution sufficient almost to neutralise (22·5 c.c.). The standard Braidy solution was added boiling and the mixtures heated in the water bath for increasing periods. The following table shows the results—

Table II

Weight of dextrose	Time of heating (min.)	Volume of $N/25$ permanganate required (c.c.)
0·00499	10	4·57
	20	5·06
	30	5·36
	45	5·26
	60	5·26
	120	5·16
	180	5·26
0·01497	10	16·82
	20	17·21
	30	17·61
	180	17·91

From these results it was concluded that 30 minutes heating with the Braidy copper solution is sufficient for complete precipitation of the cuprous oxide, the slight discrepancies in the readings being well within the experimental error. It has been stated[4] that the dilution of the Braidy copper solution by the addition of another solution causes a disturbance of the equilibrium and that it is necessary to add solid carbonate in order to obviate this. From the results obtained here and in particular those for the calibration of dextrose solution, it has been shown that even though some precipitation of black cupric oxide does occur, it does not interfere with the estimation.

Having standardised the method, it then became necessary to calibrate solutions of pure dextrose in terms of $N/25$ permanganate.

The conditions of experiment were precisely as before, i.e. the mixtures (volume=55 c.c. in each case) were heated on the water-bath just as if hydrolysis were proceeding and the almost neutralised mixture heated for $\frac{1}{2}$ hour with the Braidy copper solution. The following table gives the mean of two sets of readings on different solutions of pure dextrose. The first solution contained 1·0015 g. per litre and the second 1·0024 per litre, but the weights of dextrose present in the volumes used are considered the same in each case.

Table III

Volume dextrose solution (c.c.)	Weight dextrose (g.)	Volume N/25 Permanganate (c.c.) 1st Set	2nd Set	Mean
2·5	·0025	2·39	1·95	2·17
5	·0050	5·34	5·26	5·30
7·5	·0075	8·49	8·53	8·51
10	·0100	11·68	11·60	11·64
12·5	·0125	14·50	14·27	14·39
15	·0150	17·45	17·48	17·47
17·5	·0175	20·35	20·39	20·37
20	·0200	23·16	23·27	23·22
22·5	·0225	25·93	26·03	25·98
25	·0250	28·65	28·75	28·70
27·5	·0275	31·06	31·22	31·14
30	·0300	33·94	33·34	33·64

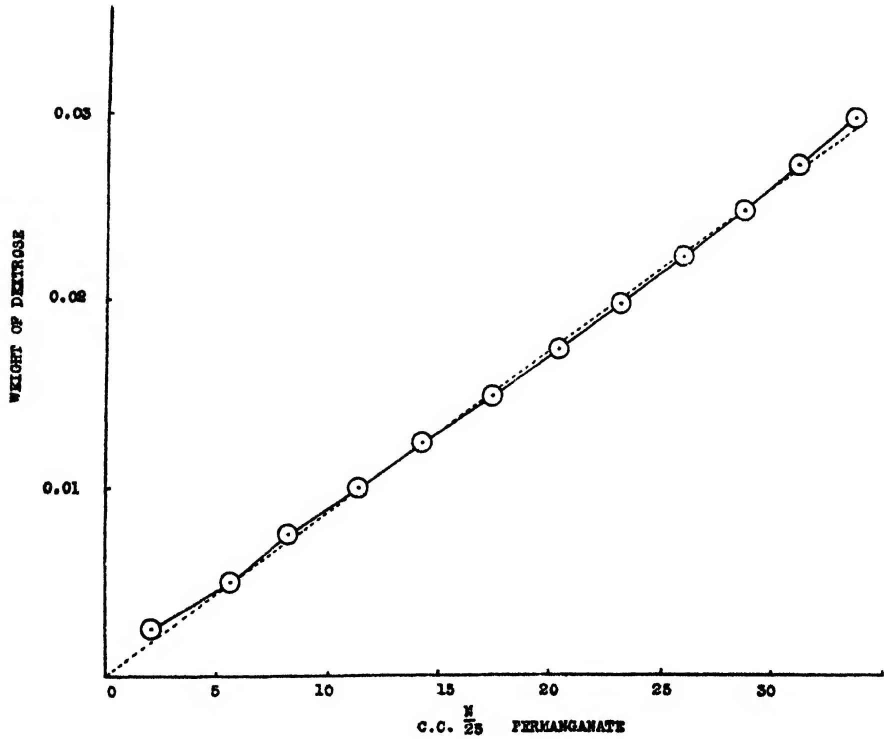

FIG. 2

The curve connecting these results is shown in Fig. 2. The straight dotted line is drawn as a mean.

The next set of experiments was undertaken in order to calibrate solutions of various starches in terms of $N/25$ permanganate under the conditions specified. For these experiments 46 g. of the air dry starch were dispersed in 2,400 c.c. water under the conditions previously specified and on cooling 50 g. of this solution carefully weighed out in each case and made up to 1,000 c c. with distilled water. The concentration of the original solution was estimated in each case by evaporating a known weight to dryness on the water

bath. Various volumes were hydrolysed under the standard conditions and the results in terms of $N/25$ permanganate are given below—

Table IV

Starch	Weight (g.)	Volume N/25 permanganate (c.c.)
Wheat	0·0042	4·1
	0·0084	9·9
	0·0091	11·2
	0·0125	15·2
	0·0167	20·5
	0·0250	29·8
Potato	0·0039	4·1
	0·0079	9·7
	0·0118	14·8
	0·0158	20·0
	0·0236	28·9
Sago	0·0078	9·2
	0·0116	14·3
	0·0155	19·3
	0·0194	24·1
Maize	0·0084	9·9
	0·0126	15·1
	0·0167	20·1
	0·0209	25·6
Rice	0·0084	9·8
	0·0127	15·3
	0·0169	20·8
	0·0211	25·8

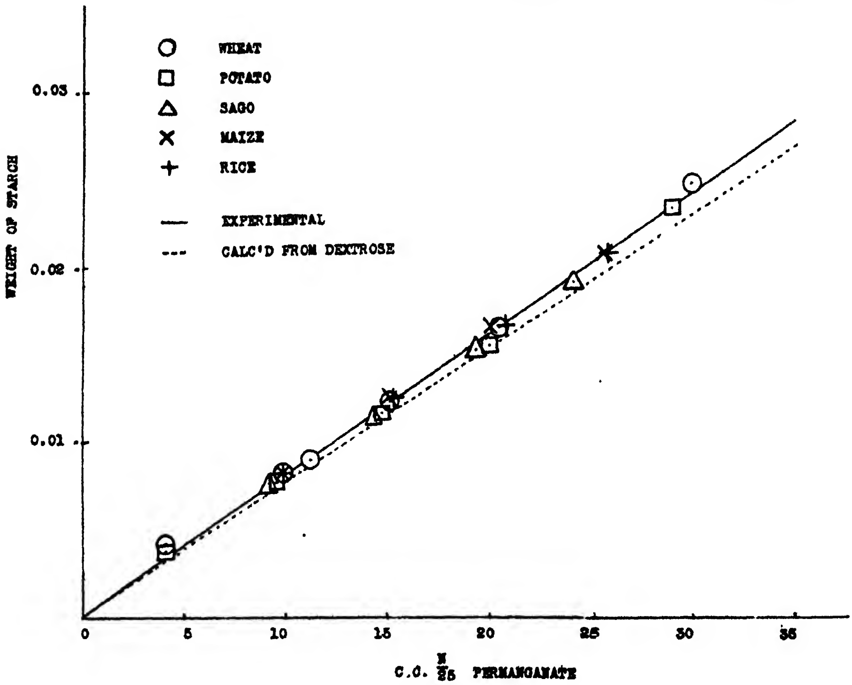

FIG. 3

Fig. 3 gives these results in graph form, and it is evident that, for the purposes of estimation, all these starches may be regarded as the same. The dotted line gives the values calculated from the dextrose curve using the theoretical factor 0·9.

DESCRIPTION OF METHOD

A weight of the cloth is chosen depending on the amount of starch present and on the type of bleaching the cloth has had, so that the titre does not exceed 35 c.c. $N/25$ potassium permanganate. With a full bleach cloth and medium starching, 1 g. is suitable. For cloths bleached to conserve weight and with medium starching 0·75 g. is better, and for green yarns on which the size is to be determined, 0·25 g. is sufficient. The cloth is cut up into very small pieces, about $\frac{1}{8}$–$\frac{3}{16}$ in. square, or in the case of yarn into $\frac{1}{4}$ in. lengths, and the weighed amount placed in a dry 175 c.c. conical flask provided with a loose glass pear stopper. 30 c.c. of water are added, followed by 25 c.c. $2N$ sulphuric acid, the latter being measured by means of a pipette. The whole is then immersed in an actively boiling constant level water bath for *exactly* 2½ hours. At the end of this period the fabric is filtered off through a fine-grained sintered Jena glass funnel fitted into a second 175 c.c. conical flask using slight suction. It is advantageous to remove all the residual fabric from the flask before using any wash water and this can be done quite readily after a little practice. The flask is then rinsed out with two successive amounts of 5 c.c. distilled water, the latter being passed through the filter in order to wash the residual fabric; each lot of 5 c.c. is drawn through the funnel separately. To the filtrate is then added one drop of methyl orange solution and the solution nearly neutralised with $2N$ sodium carbonate (approximately 22·5 c.c.). When green yarns and boiled goods are being tested care must be taken at this point to add the alkali slowly and with constant shaking, as otherwise the hemicelluloses, pectins, etc., present, produce such a lowering of surface tension as to cause the liquid to froth over. The solution is then brought to the boil and to it is added a boiling mixture of—

95 c.c. Braidy alkali.
5 c.c. ,, copper sulphate solution.

exactly as used for the determination of copper number and the whole immersed in the boiling water-bath for half an hour. The precipitated cuprous oxide is then filtered off through a layer of purified asbestos contained in a coarse sintered glass funnel and the flask washed out once with 1% sodium carbonate solution followed by twice washing with water. In each case the wash liquid is poured over the cuprous oxide and drawn through by suction. The filter flask is then replaced by a smaller one of about 250 c.c. capacity and two successive amounts of 15 c.c. of Braidy iron solution are poured over the asbestos after rinsing through the conical flask. A few seconds are allowed to elapse before drawing the liquid into the flask in order to give the iron solution sufficient time to dissolve all the cuprous oxide. The flask is then rinsed twice with $2N$ sulphuric acid, the liquid in each case being poured over the asbestos. The filtrate is then titrated directly in the filter flask with $N/25$ potassium permanganate solution until a persistent pink coloration is observed. The same asbestos may be used for a number of determinations provided that each time after using, it is well washed with water followed by 1% sodium carbonate solution. Care should also be taken to see that the asbestos covers the sintered glass completely.

It is necessary with each determination to conduct a "blank" experiment, i.e. with the fabric before starching. The blank should be done at the same time and side by side with the flask containing the starched sample. The difference between the titre of the starched sample and that of the blank multiplied by the factor 0·00082 gives the weight of starch on the fabric taken.

The results in this paper are calculated as a percentage of the dry (anhydrous) starched fabric assuming a moisture content of 6·0%, the error involved in this assumption being well within the error of experiment.

If, as is often the case, the unstarched fabric is not available for a blank determination, it has been found practicable to use a desized sample of the starched fabric. The desizing solution employed is made up by dissolving 3 g. common salt in 1 l. of water at 50° C. and then adding 3 g. Novo Fermasol and stirring until dissolved. The fabric is immersed in the solution for ½–¾ hour at 50° C., after which it is well washed and the treatment repeated with a fresh desizing solution. The temperature of the solution should not rise much above 50° C. as higher temperatures destroy the enzyme. The fabric is well washed and allowed to dry in the air. Several different samples may if necessary be desized together.

Novo Fermasol has no reducing effect on the Braidy copper solution as the following experiment shows—

30 c.c. Novo Fermasol solution (as above),
25 c.c. $2N$ sulphuric acid

were hydrolysed for 2½ hours, followed by ½ hour treatment with Braidy copper solution.

Volume 0·984 $N/25$ permanganate required = 0·1 c.c.
Volume 0·984 $N/25$ permanganate required for blank = 0·1 c.c.
∴ Volume permanganate required for Novo Fermasol = 0

Again Novo Fermasol does not remove any appreciable quantity of reducing matter from the fabric as is shown by the following figures—

Sample of unstarched linen fabric bleached to conserve weight (1 g.).
Volume $N/25$ permanganate = 31·55 c.c.
Same sample after desizing twice = 31·46 c.c.

That the Novo Fermasol removes practically all the starch is shown by the following result, which is the mean value of six readings obtained on desizing the same sample of linen fabric after starching with light, heavy, and medium starches; two separate desizings being made in each case.

Volume $N/25$ permanganate = 31·6 c.c.

In the finishing of many classes of goods softening materials such as soaps, soluble oils, etc., are frequently introduced into the starching mixtures, and in order to determine whether these substances exerted any reducing action on Braidy copper solution the following experiments were made. Solutions of the following were then made up in distilled water—

¼% Lever's Textile Soap Flakes.
¼% Turkey Red oil (sulphonated castor oil).
¼% Soluble oil (Castor Oil Soap base).

30 c.c. of these contained approximately 0·075 g. of the material.

The following mixture in each case was hydrolysed for 2½ hours and the permanganate titre determined as before—

30 c.c. solution.
25 c.c. $2N$ sulphuric acid.

The blank estimation gave 0·075 c.c., 0·9877 $N25$ permanganate.

Table V

Solution used	Titre	Actual volume of permanganate used
Levers Textile Flakes	0·075	—
Turkey Red Oil	0·075	—
Soluble Oil	0·075	—

These results show that it is unnecessary to remove soaps and soluble oils from the fabric before determining starch.

As a final check on the method, a sample of unstarched linen damask was weighed dry and then padded out with a hot solution of wheat starch of approximately 1·8% concentration, squeezed out between rubber rollers and dried to constant weight at 105° C.

Weight fabric dry before starching = 11·8896
Weight fabric dry after starching = 12·0410
Weight starch = 0·1514
Percentage of starch on dry fabric = 1·26

A sample of the starched fabric was allowed to condition in the air and 1 g. hydrolysed by the standard method.

Titre before starching = 19·61 c.c. $N/25$ permanganate.
Titre after starching = 34·96 c.c. ,, ,,
Difference due to starch = 15·35 c.c. ,, ,,
∴ Percentage of starch on dry fabric assuming 6·0% moisture content = 1·34

For purposes of comparison the sample of starched fabric and that before starching were desized twice under the conditions already specified.

Percentage loss in weight due to desizing unstarched fabric = 0·073
Percentage loss in weight due to desizing starched fabric = 2·768
Actual percentage loss = 2·695

It will be observed that the actual loss is obtained by subtracting the percentage loss calculated on the unstarched from that calculated on the starched fabric, but the error involved is so small as to be within that of experiment. The results indicate that the loss on desizing cannot be returned as starch.

In order to show what differences, if any, were involved by hydrolysing various weights of the starched fabric, another sample of linen damask was padded out with an approximately 1·7% solution of wheat starch and allowed to dry. Amounts of 0·5, 0·75, and 1·0 g. of the starched fabric were taken and hydrolysed under the standard conditions, a separate blank test being made with each weight. The following table gives the percentage of starch calculated in each case.

Table VI

Weight fabric taken	Titre in c c $N/25$ permanganate due to starch	Percentage of starch on dry fabric
0·5	5·98	1·04
0·75	9·09	1·06
1·0	11·36	0·99
*0·25 }	3·36	1·17
0·5 }	6·00	1·05
0·5 }	3·05	0·53
1·0 }	5·52	0·48

* These results were obtained on a sample of linen damask bleached to conserve weight and starched under works conditions with two different strengths of starch

APPLICATION OF METHOD

The following table gives the results of the estimation of a series of samples of linen damask all bleached from the same grey web and starched and finished under works conditions. The copper numbers are included for comparison—

Table VII

Sample	Titre of unstarched fabric	Copper number of unstarched fabric	Titre of starched fabric	Copper number of starched fabric	Titre due to starch	Percentage starch on bone-dry fabric
No. 1 bleach	19·41	0·37	21·78	0·38	2·37	0·21
No. 2 bleach	34·63	1·29	37·40	1·20	2·77	0·24
Weight-conserving bleach	29·88	1·19	33·05	1·06	3·17	0·28

For comparison purposes, also, the titre of the grey fabric from which the above three samples were bleached was estimated by hydrolysing 0·25 g. and was found to be 71·9 c.c. $N/25$ permanganate per gramme of the air-dry fabric.

The following set of samples was produced by starching pieces of linen damask bleached to conserve weight all from the same web through fine, medium, and heavy starching mixtures under works conditions. The pieces were sewn in behind webs that were being starched through the starching mangle with the particular starching mixtures involved. Side by side are given the net losses in weight, i.e. the difference between the loss on the starched and that on the unstarched fabric, found on desizing the samples by the old method. In addition to these results are given the values obtained for a plain cotton cloth starched with a heavy starching mixture—

Table VIII

Sample	Percentage net loss on desizing calculated on dry starched fabric	Percentage starch by hydrolysis calculated on dry starched fabric
Linen bleached to conserve weight		
Fine starching	0·79 ...	0·26
Medium starching	1·33 ...	0·48
Heavy starching	1·99 ..	1·11
Plain cotton—		
Heavy starching	1·53 ..	1·54

APPLICATION OF THE METHOD TO THE ESTIMATION OF STARCH SIZE ON GREY, BOILED, AND BLEACHED FLAX YARNS

0·25 g. was hydrolysed in each case excepting that of the ¾ white Courtrai when 0·5 g. was used. A sample of the unsized yarn in each case was available and served as the blank. The following table gives the percentage of starch on the sized yarns under testing-room conditions of 75% relative humidity and a temperature of 66° F. calculated from the change in lea of the unsized yarn. The amount of starch estimated by hydrolysis is also given and for purposes of comparison is calculated as a percentage of the sized yarn under testing-room conditions.

The moisture contents are as follows—

	Testing-room conditions (%)	Ordinary air-dry conditions of weighing (%)
Green	11·5 ...	8·5
Boiled	10·0 ...	8·0
¾ Bleached	9·5 ...	7·5

Table IX

Sample	Percentage starch from change in lea. Testing-room conditions	Percentage Starch by Hydrolysis 1st Set	2nd Set	Mean
43's Courtrai Line, green	3·26	2·38	2·49	2·44
43's Courtrai Line, boiled	3·00	3·10	3·03	3·07
43's Courtrai Line, ½ bleached	2·31	2·49	2·50	2·50
43's Courtrai Line, boiled	5·29	3·59	3·76	3·68
43's Irish Line, boiled	2·62	3·46	3·34	3·40
43's Russian Line, boiled	5·77	3·10	3·23	3·17

DISCUSSION OF RESULTS

The method for the determination of starch described in this paper occupies considerably less time than that of determining the loss on desizing and in most instances, particularly where soluble substances other than starch are present, is more accurate. In routine determinations where the same fabric has been starched with varying concentrations of starch, 11 estimations and the blank may be carried out at a time on a water-bath provided with 12 holes, the whole operation occupying 3–4 hours. When different samples of fabric are to be estimated portions of each may be desized together in the same vessel and allowed to dry after washing and six estimations may be carried out at a time.

From the results given graphically for dextrose and for the various starches, it will be seen that the points do not lie exactly on a straight line but on a curve slightly convex to the horizontal axis. The mean straight line drawn in each case is, within certain limits (approximately 7·5 c.c.–35 c.c. $N/25$ permanganate titre), well within the experimental error involved in the estimation. The experimental curve obtained for the various starches differs from that obtained by calculation from the dextrose curve using the theoretical factor 0·9. The factor connecting the experimental starch curve with that obtained for dextrose is 0·943, which is in good agreement with the figures given in the literature, viz. 0·93–0·95[5, 6, 7]

Again, from results given, the figures for starch obtained by using various weights of the fabric show a certain discrepancy, the smaller weight tending to yield a slightly higher result. The accuracy, however, is again well within the limits of practical requirements.

With regard to the actual strength of sulphuric acid used for hydrolysis, it is advantageous, though obviously not essential, to keep to a strength of exactly twice normal, since by this means blank readings for any particular weight of fabric are comparable with one another.

In adapting the method for the estimation of starch size on flax yarns it is essential that the blank, i.e. the unsized yarn be available at least in the case of the green yarn, as a satisfactory blank could not be obtained by a desizing treatment which, in addition to the starch, would remove a considerable amount of reducing matter. Table IX compares the results obtained from the change in lea consequent on sizing, with those obtained by the present method. The change in lea method is open to criticism on the ground that it does not take into account the effect of shrinkage or extension of the yarn which may be considerable and which would tend to give high or low results for the starch.

An examination of the results obtained by both methods, especially those in the case of the three boiled yarns all sized with 5% sago under comparable conditions, would appear to indicate that those obtained from the change in lea are not as reliable as those obtained by hydrolysis.

31st July 1930

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38—THE NATURE OF THE DUST IN THE AIR OF COTTON CARD ROOMS

THE BRITISH COTTON INDUSTRY RESEARCH ASSOCIATION

INTRODUCTION

This communication is an abridgment of a report made in April 1928, by the British Cotton Industry Research Association to the Federation of Master Cotton Spinners' Associations, and based mainly on investigations by Messrs. T. B. Bright, E. Rhodes, and F. Summers.

The work began in May, 1925, and was extended to seventeen card rooms in mills dealing with (*a*) Indian cottons—both alone and in mixings with American cottons; (*b*) American cottons; (*c*) Egyptian Uppers; and (*d*) Egyptian Sakel. The card rooms were selected so as to obtain the widest possible range of conditions as regards the type of cotton, the dimensions and lay-out of the room, the efficiency of the ventilation, and the method of stripping. It was necessary at the outset to examine critically the available methods for sampling the air of a card room and counting the particles of dust in a sample. In this connection, acknowledgment must be made of previous work on the subject by Dr. E. L. Middleton, of the Medical Branch of the Home Office[1]. The chief problem in such investigations was found to be the interpretation of the results because of the frequent changes in the composition of the atmosphere at any given spot in an average card room.

The report is divided into three parts. Part I describes the methods; Part II gives some account of the results obtained when using the methods to investigate (*a*) the buoyancy of the dust and the effect of ventilation on its suspension, and (*b*) the effect of humidity, height of ceiling and so forth on the dust content; Part III discusses the composition of the dust from a chemical and biological standpoint, but does not attempt to draw any conclusions on health questions.

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Director of Research

I—METHODS OF INVESTIGATION

Nature of the Dust

The dust liberated from raw cotton as it undergoes the carding process is composed of fine sand, particles of leaf and seed coat, fragments of mould fungi together with portions of cotton hairs ranging from very minute fractions to almost complete hairs. The particles are comparatively speaking of two sizes, either very large or very small. The dividing line between the classes is strongly marked for there is an almost complete absence of intermediate sizes. The larger particles are generally fractions of cotton hairs all greater than 0·01 mm. (1/2540 in.) so that individually they are visible to the naked eye, whilst the smaller particles have their greatest dimensions less than 0·01 mm. and are individually invisible.

This segregation according to size is of considerable practical importance. The casual observer on entering a card room sees only the larger particles, and is at once inclined to ascribe to them a greater importance than to the enormous numbers of smaller, invisible particles, whilst the estimation of the numbers of each type entails the employment of two distinct methods, each suitable for one type only. The smaller particles are apparently thrown out into the air only by the operation of the working parts of the carding engine, but the larger hair fractions may be liberated from the lap as it enters the card or from the sliver which leaves it, and they are also particularly noticeable over the draw frames.

The Larger Particles

These were estimated by means of a settlement method. Originally it was hoped that it would be possible to employ for this purpose the settlement

dust counter described by Dr. J. S. Owens[2], but even in the dustiest atmosphere encountered, the number of particles deposited on the cover slip from a column of air 100 cm. (39 in.) in height did not work out at more than one per microscope field. Accurate counting was therefore impossible, and the use of the instrument was abandoned.

The method finally adopted was the following—A cylinder of length 100 cm. (39 in.) and internal diameter 10 cm. (3·9 in.) was constructed to fit over a round glass dish coated with a film of glycerin. The latter was protected by a shutter which could be withdrawn through a slot in the base of the cylinder. The cylinder was filled with the air of the card room under test by sweeping it through the air axially, and then placed in position over the glass dish with the shutter withdrawn, a lid being put over the top of the cylinder to prevent further dust entering. The dust was allowed to settle for five minutes, at the end of which the shutter was replaced and the dish removed to a clear atmosphere where a closely fitting glass cover was substituted for the shutter. On return to the laboratory the dish was placed on black velvet, illuminated from above, and the number of hair portions counted with the aid of a hand lens.

No claims to great numerical accuracy can be made for such a rough method but the results were sufficiently good to show that the number of whole cotton hairs in card room hair was very small, whilst the number of larger hair fractions was negligible in comparison with the amount or number of particles of fine dust.

The results of the two settlement experiments are shown in Table I. In Mill No. 1 a low grade of Egyptian Uppers and in Mill No. 2 an ordinary Texas mixing was being carded.

Table I

Area measured = 25 sq. cm. (3·875 sq. ins.) Vol. of air = 2,500 cc.

Mill	Number of Hairs or parts of Hairs	Period of Settlement	Incidence
No. 1	119	5 min	1 in 21 c.c.
	280	15 ,,	1 in 9 c.c.
No. 2	77	5 ,,	1 in 32.5 c.c.
	177	15 ,,	1 in 14 c.c.

Results such as these make it appear that more refined methods for the enumeration of the larger particles were to be regarded as of secondary importance and, therefore, attention was concentrated on elaborating a method of counting the finer particles, accuracy and speed being essential features of such a method.

The Finer Particles

Except where otherwise stated all samples were taken by means of the Jet Extraction Apparatus designed by Dr. J. S. Owens[3]. This extracts a known volume of air from the atmosphere under investigation and concentrates the fine dust particles suspended in it on a microscope cover glass. The area of the deposit is small (10 mm. × 0·1 mm., i.e. 0·4 in. × 0·04 in.) so that even at high magnifications one field of the microscope contains many particles that may easily be counted or photographed. Manipulation of the instrument is simple and it gave complete satisfaction throughout the investigation.

Method of Collection—Samples of air for examination were taken at average breathing height, i.e. at a height of five feet from the floor level. Other samples were taken near those working parts of the card which seem to be the chief sources of dust production. It was also found necessary to sample the air immediately outside the card room to ascertain the number and character of the particles entering from outside.

Method of Counting—Since it was desirable to express all results as the "number of particles per c.c. of air" it was necessary to make a computation on each deposit. This was done as follows—The cover glass bearing the deposit was attached directly to a 3 in. × 1 in. glass slide by two layers of the adhesive supplied with the instrument. The metal rings supplied for mounting were not used since they raised the cover glass to such an extent that the sub-stage condenser could not be brought into focus upon the dust. This was examined by means of a Zeiss fluorite oil-immersion objective of focal length 1·8 mm. and NA.1·3. A Pointolite lamp provided the illumination. The microscope stand was fitted with a binocular body and a network micrometer was mounted permanently in one of the pair of × 10 eyepieces used.

It should be emphasised that critical illumination and a binocular microscope are essential to satisfactory counting.

In order to count the particles the deposit was made to travel across the field by means of the mechanical stage. No particle was included in the computation unless it had one dimension of at least 0·002 mm. (1/12,000 in). This arbitrary omission of the smallest particles was adopted as a precautionary measure against including in the computation foreign particles commonly present in the atmosphere but having no relation to the dust produced during the carding process. These are chiefly smoke particles which occur roughly to the same extent both inside and outside a card room. Middleton[1] (p. 443) apparently excluded from his computations all the smoke particles which he was able to detect but in the present investigation this procedure was found to be dangerous and capable of producing considerable errors in the computations. A single dust particle may cover from view several smoke particles, so that a control computation of the smoke particles in the air outside the card room affords no help in arriving at a true estimate of the number of dust particles in the room. The choice of the arbitrary standard of size mentioned above furnishes the best means of discounting the presence of smoke particles for, owing to their smallness, very few of these are included, whilst on the other hand few dust particles are omitted. It may be emphasised at this point that the enumeration of particles smaller than 0·002 mm. (1/12000 in.) as suggested by Middleton[1] (p. 443) in the records of dust produced by grinding, would tend to vitiate the numbers owing to possible serious errors apart from errors due to fatigue or eyestrain.

In the earliest tests, particles were enumerated at ten points in each deposit, at least ten deposits being taken, but later 25 tests were taken and the particles counted at five points in the deposit, a statistical analysis having shown that an increase in the number of samples and a decrease in the number of observations from each gives a more trustworthy mean, provided the observations are distributed evenly over the length of the deposit and that the ends are avoided.

By means of a Leitz eyepiece camera, photographs of the deposit were taken at three magnifications. Those at the highest (× 1,900) formed permanent records of the composition of the dust produced under different

conditions and also provided sufficient evidence to enable certain features of the investigation to be elucidated, such as the effect of grinding and the occurrence of mildew spores.

II—THE EXAMINATION OF THE AIR OF A CARD ROOM

A single deposit does not give an accurate indication of the state of the card room atmosphere. The number of particles per c.c. in the latter may not only vary from place to place in the same room but also from minute to minute. Dust storms frequently arise locally, where cleaning, dusting, stripping, and grinding are being carried out, whilst the ventilating system and the movements of the operatives also contribute towards the variation. It can be readily observed that one of the places in a card room where the dust is most actively produced is inside the chains of the flats, but among the tests made by Middleton[1] (p. 438) the sample taken from the general air of the room contained the same number of particles as one taken inside the chain of the flats of a working carding engine. This is the place where dust is being most actively produced but in view of the variations discovered during the present investigation Middleton's result is not surprising.

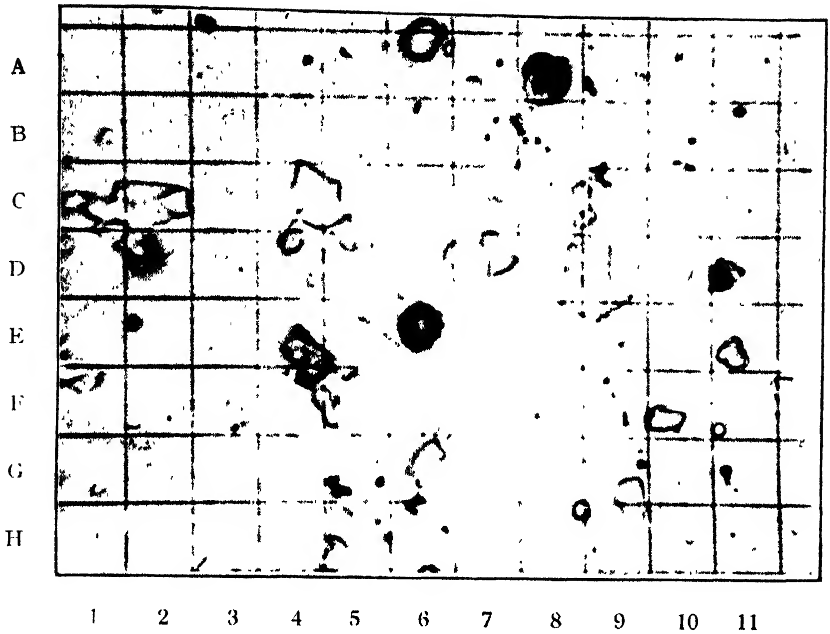
In any discussion of the results of dust counts the warning entered by Middleton becomes of the greatest importance. This was to the effect that "the three main variables of the card room (1) the kind of cotton (2) the general conditions of the room and (3) the ventilation system, may vary within such wide limits that no basis of comparison can be said to exist between one set of conditions and another. The effect of this variation on the value of dust determination is such as to set aside any conclusion to which this or that may seem to point . . ." In addition, although the result of a particular test gives an accurate determination of the number of particles in a card room atmosphere this result is true only for the particular set of conditions at the time the sample is taken. Day-to-day variations are generally so great that to enable any judgment of value to be formed of the true working conditions it is essential to examine a very large number of samples taken in as many parts of the room as is practicable and on a considerable range of working days. Indeed, it would appear to be very difficult to compare the state of the air in different card rooms by the enumeration of dust particles.

A valid comparison of two card rooms must take into account the kind of cotton, the system of ventilation employed, the amount of air space, floor space, number and arrangement of machines working, and the general cleanliness of the place. Unfortunately, the variation of these factors is very great and it has not proved possible to find a comparative set of conditions with the chance of varying one of them.

(1) Factors Affecting the Dust Content of a Card Room

(i) *Height*—Here it has not been possible to obtain data of any value on the effect of the card room height. This is due to the fact that for comparative purposes no two card rooms have been available in which conditions were sufficiently alike except for height and it is doubtful whether these conditions will ever be realised.

(ii) *Ventilation and Buoyancy of the Dust*—Some of the particles that compose the dust of card room air are sufficiently buoyant to keep floating in the air in the absence of ventilation currents. The various mildew spores will fall into this particular class. Under similar conditions the



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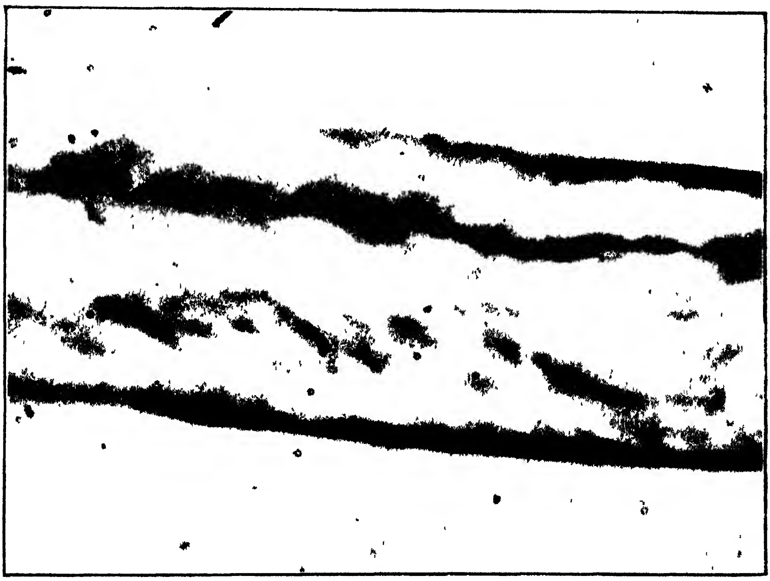


No. 2

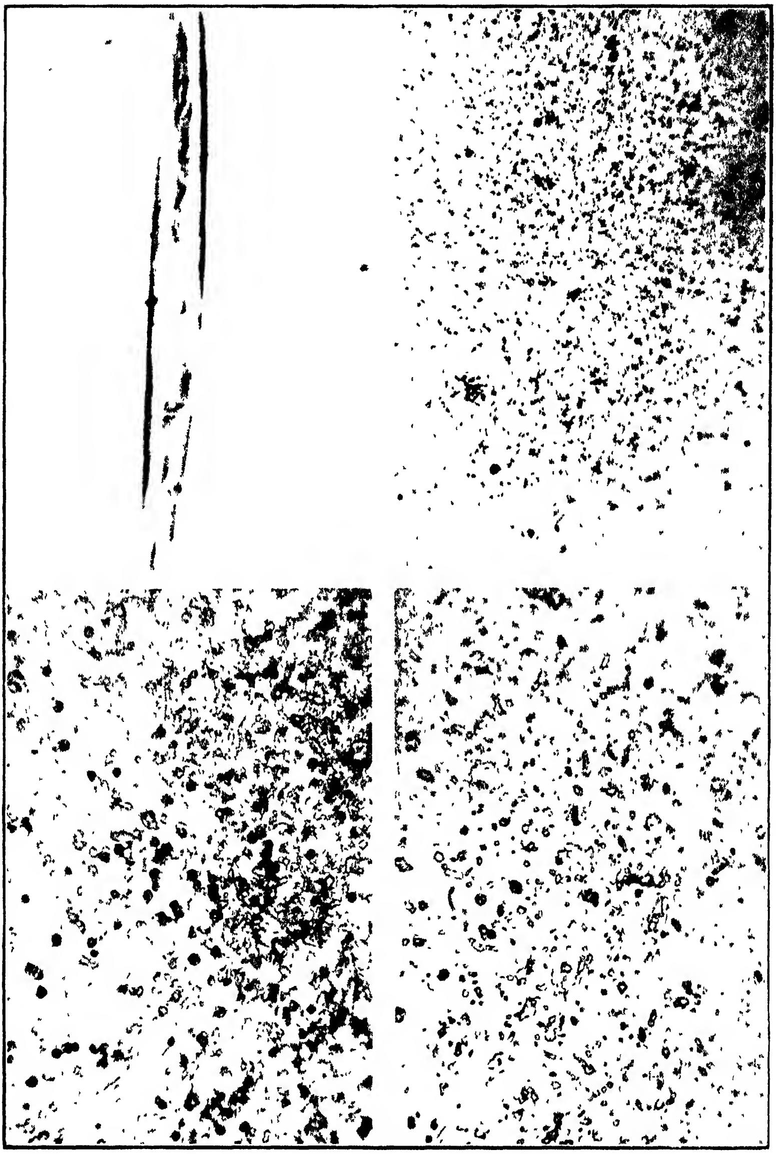
PLATE I

No. 1 Illustrates the method of counting and shows card room dust through a square ruling in the microscope to facilitate counting Side of square = 0·0043 millimetre E6 shows a mildew spore, B10, smoke particles, and C4, a fragment of cotton hair Magnification × 2000.

No. 2—One five-hundredth of an inch of a Sakel cotton hair at same magnification × 2000.

No. 3

No 4



No. 5

No. 6

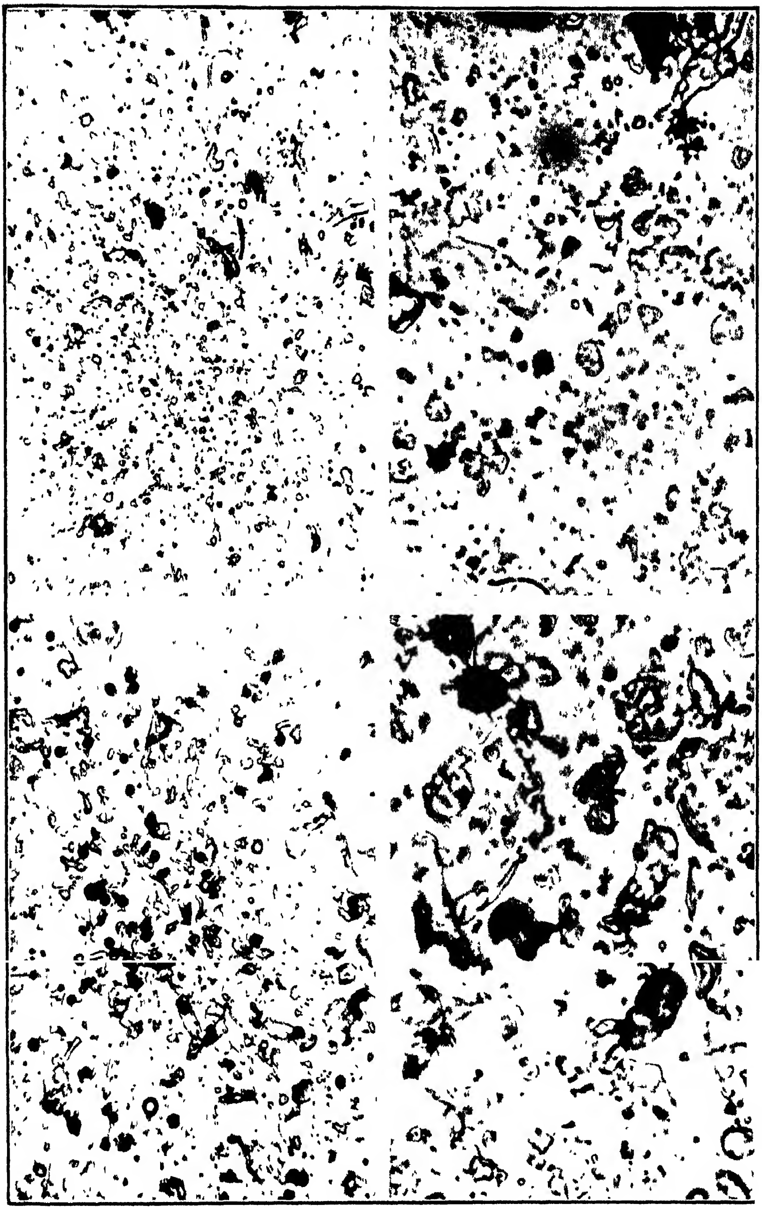
PLATE II

Magnification $\times$ 360.

No. 3—One seventy-fifth of an inch of a Sakel cotton hair.
No. 4—Smoke particles from the air at the Shirley Institute
No. 5—Dust from inside the chain of flats on card working Egyptian Uppers.
No. 6—Dust from inside the chain of flats on card working Texas cotton.

No. 7

No. 8



No 9

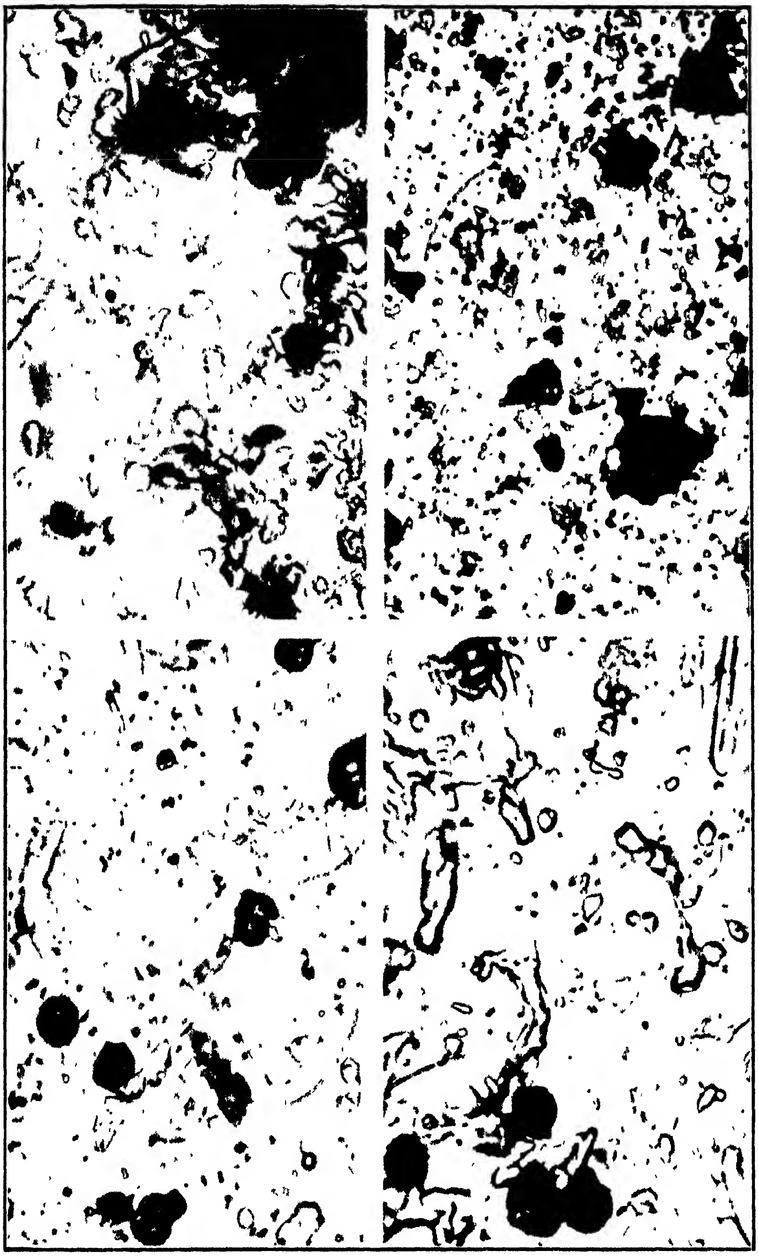
No. 10

PLATE III

No 7 - Dust from air 5 feet above floor level between cards working Texas cotton × 360.
No. 8 Ditto × 1500
No 9 - Dust from air 5 feet above floor level between cards working Egyptian Uppers × 360.
No. 10 - Ditto × 1500.

No. 11

No.



No 13

No 14

PLATE IV

Magnification × 1500

No 11 Dust from air 3 inches above stripping brush stripping cylinder of card working Egyptian Uppers.

No. 12 -Dust from air 6 inches above cylinder grinder grinding both cylinder and doffer after thorough cleaning Shirley Institute experimental card

No. 13- Dust from air 6 inches above doffer hood Card grinding and surrounded by other cards working Egyptian Uppers.

No 14—Dust from air close to grinding roller when grinding has just commenced on card working Egyptian Uppers

remainder of the particles would fall more or less rapidly to the ground and these form the great proportion of the dust.

When ventilation is employed the particles first mentioned are carried away in the air currents, but the direction taken by those of the second class is a compromise between that which they would take under the action of gravity and under that of the air current. As the influence of this latter weakens, the effect of the gravitational pull increases so that these particles also finally reach the ground.

Consequently, any system of ventilation by which horizontal currents of air are created, tends to keep particles floating in the air which would otherwise sink to the ground.

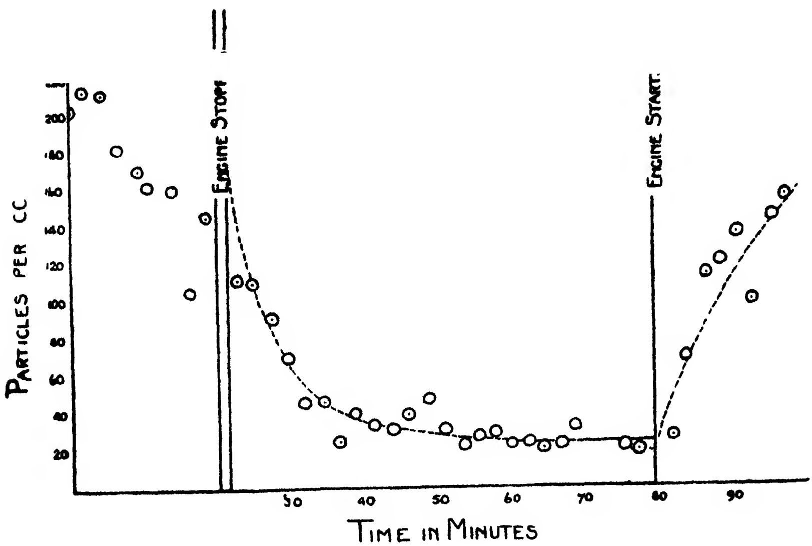


Fig 1

The following set of observations in a card room illustrates the behaviour of the two kinds of particles when ventilation ceases as it does in the dinner hour break when the engine is stopped. Nine air samples were taken at two-minute intervals during the 20 minutes immediately before the stoppage of the engine, i.e. while carding was proceeding. It should be noted that under these conditions the number of particles per c.c. in the place where the sample is taken may vary very greatly from minute to minute. This is due to sudden "dust storms" created locally by such causes as cleaning and sweeping operations, traffic, and the opening of doors. The time available for the manipulation of the apparatus only allowed of one test for each interval.

After the engine had stopped and both dust production and ventilation currents with it, single samples were taken, as nearly as possible at two-minute intervals, both during the dinner hour and also during the 20 minutes which immediately followed the re-starting of the engine. The results are shown by the graph in Fig. 1, from which it can be seen that on the stopping of the engine the number of particles per c.c. in the air fell during the first 20 minutes to about 20–30, the number remaining approximately constant for the next 35 minutes. On the engine being re-started the number of particles rapidly increased and in 15 minutes it had practically reached the original level again.

It is clear, therefore, that there is a constant tendency for the majority of the dust particles to settle by their own weight and this tendency might be taken account of and encouraged by the system of ventilation employed. Many systems, owing to the situation of the extracting fan, work against gravity and, on that account, encourage the heavier particles to remain in the atmosphere. The more elevated the situation of the air inlets, and the lower that of the suction outlets, the more this tendency of the particles to settle will be encouraged, and the more efficient should be their removal, but this may only be true in the neighbourhood of the outlets.

(iii) *Humidity*—It was necessary in order to study most easily the effect of humidity to work in a non-humidified mill. In a humidified card room working for finer counts not only is the production of dust particles low but there is no great variation of the humidity. In the card room actually tested, humidities ranging from 37·4 to 54·4 per cent. were experienced. These were due to the meteorological conditions prevailing at the time of testing and, naturally, effects due to variations of temperature and wind accompanied those due to humidity. No evidence was obtained of a decrease of dust production with increase of humidity since the countings in this particular card room were almost equal at these humidities as shown by the black rectangles of Fig. 2. On the other hand a temporary disturbance of the ventilation caused a tremendous rise in the number of particles as indicated by the shaded rectangle in Fig. 2, R.H.=47 per cent.

It should be noted that the only method of investigating this aspect of the problem accurately would be to carry out the work in a humidified card room in which the working of the humidifiers could not only be varied but stopped altogether when required. This would involve considerable interference with the working of the room with consequent loss, and would probably be an unwarranted tax on the mill concerned.

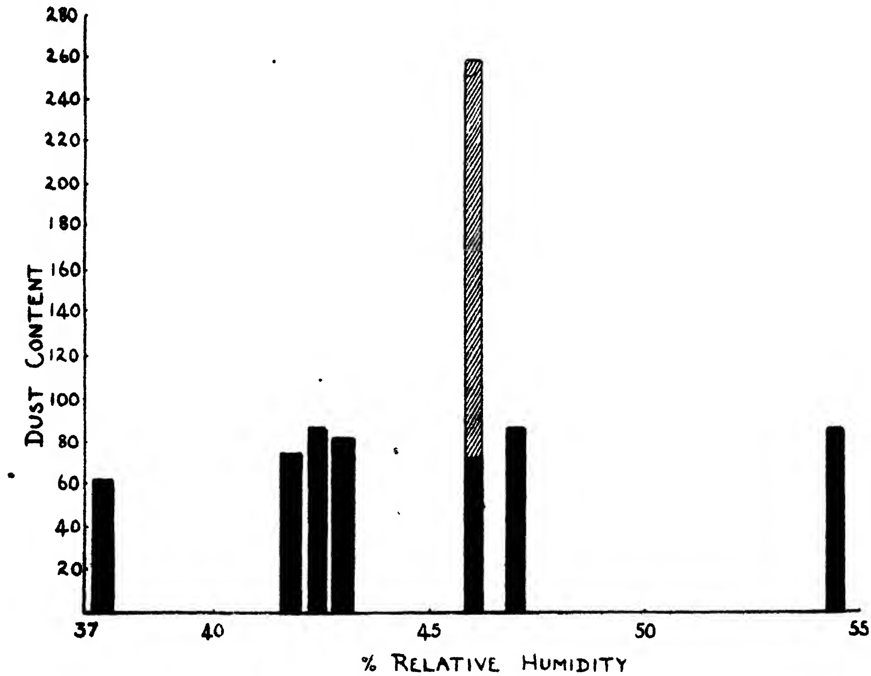


FIG. 2

(iv) *Stripping*—With Cook's vacuum stripping method there is no possibility of dust escaping into the air, but where the hooded brush is used any weakness in the vacuum pump causes a dense cloud of dust to be discharged into the faces of the strippers immediately the brush engages.

The following pressure readings, Table II, obtained with a vacuum gauge, give an idea of the fluctuations which may be encountered in the suction at the hood.

Table II

	Mill A	Mill B
	inches	inches
No stripping	20—25	5—15
One stripper working	15	0
Two strippers working	12	—
One trap left open	5	0

If the stripping is to be clean the pump should be able to maintain a vacuum of about 10 in. while stripping is in progress. It has been observed that dust storms are often produced by starting the brush revolving before connection is made to the vacuum pipe or by neglecting to open fully the tap on this pipe. On the latter account care should be taken to ensure that the tap works quite freely.

(v) *Grinding* has little effect on the dust content of the card room air; at the moment when grinding is commenced the operative adjusting the rollers may receive a considerable discharge of dust in his face and if a sample is taken immediately above the doffer or cylinder while grinding is taking place numerous black particles of carborundum will be found if the roller is new, but when the roller has been fully ground in the number of such particles is small. Up to the present they have been definitely detected only in special samples taken close to the grinding. The probability is, therefore, that these particles are so heavy that they fall immediately to the floor and can be left almost completely out of consideration. To obviate the sudden discharge when grinding commences it would appear necessary to enclose the rollers in a hood connected to the vacuum system and maintain this hood in position during the few minutes of grinding.

(vi) *Dust Production by the Draw Frames*—Tests of the atmosphere above the draw frames have been carried out in two mills which were working dusty cotton. The majority of the countings fell below those of the cleanest card room yet investigated, the highest figures being obtained at frames situated in the direct line of the air current from the cards to the blowing room.

The action of the frames tends to set free a number of whole hairs or parts of hairs. These, being visible to the naked eye, attract immediate attention but as they fall comparatively rapidly and do not float like the finer dust particles from the card there is much less chance of their being inhaled.

III—BIOLOGICAL AND CHEMICAL COMPOSITION OF THE DUST

The Live Organisms of the Dust.

In order to collect these, 50 litres of air were aspirated as rapidly as possible through a plug of anhydrous sodium sulphate contained in a glass tube of the form shown in Fig. 3. The internal diameter of this tube was $\frac{3}{4}$-in. and its length 8 in., a slight constriction being present about 2 in. from one end. Above this was placed a plug of sterilised bacteriological cotton

wool which supported a thickness of about ⅛-in. of the sodium sulphate. The mouth was plugged with cotton wool and the whole then sterilised at 110° C.

To draw the air through, two ten-litre aspirators working alternately were used, and the tube was disconnected and replugged when the required volume had been aspirated. On return to the laboratory the sodium sulphate was dissolved in a litre of sterile normal saline from which 1 c.c. was then transferred by a sterile pipette to a tube of melted agar. This was poured into a Petri dish, allowed to cool and then placed in the incubator. Cultures were also made at dilutions of 1/10 and 1/100.

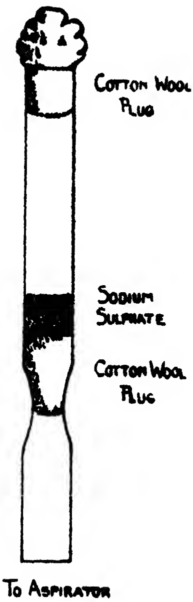


Fig. 3

Four methods of culture were used, namely, nutrient (beef extract) agar at 25° C. and 37° C., nutrient gelatine at 20° C. and beer-wort-agar at 25° C. The latter medium was adopted as the most suitable for the fungi present.

A number of typical results are set out in Table III. Two features of the table are probably of significance, namely, the ratio of live organisms to dust particles and the incidence of spores of the *Aspergillus niger* group. The number of organisms that can grow at 37° C. and which on that account ought probably to be regarded as potentially pathogenic, may form as many as one per cent. of the total dust content. Amongst these the *Aspergillus niger* group is invariably strongly represented. The fungi that grew at the lower temperatures were mainly species of *Penicillium* and *Aspergillus* with the *Aspergillus niger* group as the dominant species.

It should, however, be pointed out that the beer-wort-agar used for the culture media as being most suitable for the growth of moulds would not always permit the growth of some bacteria known to be present in most raw cottons, and, therefore, the numbers given for all organisms in the air samples will be low.

Table III
Numbers of Bacteria, etc., in the Air of Five Card Rooms

No. of Mill	Type of Cotton	Particles per c.c. in Air	Organisms growing at 37° C. excluding *Aspergillus niger*	Ratio Organisms to Particles	Organisms growing at 25° C. excluding *Aspergillus niger*	Ratio Organisms to Particles	Total number Fungus Spores per c.c.	*Aspergillus niger* Spores per c.c.
1	Egyptian Uppers ...	160	1·6	1/100	1·0	1/160	3·16	3·0
2	American and Indian ...	145	0·79	1/180	1·0	1/150	0·12	0·06
3	American and Indian ...	60	0·37	1/160	0·27	1/230	0·11	0·06
4	Sakel and Sea Island ...	36	0·22	1/160	0·36	1/100	0·25	0·24
5	Sakel ...	30	0·32	1/95	0·2	1/150	0·22	0·20

The ratio of the number of organisms of all kinds to the total number of dust particles in the atmosphere did not vary greatly from test to test, but it was otherwise with the spores of the *Aspergillus niger* group, as both the experimental data and the photomicrographs show (Plate II, 5; Plate III, 9; and Plate IV, 13). They rarely formed less than 50 per cent. of the total number of fungus spores and at times exceeded 90 per cent.

The Chemical Analysis of the Card Room Dust

The form of scrubber shown in Fig. 4 was employed to collect the dust, standard pieces of laboratory glass-ware being employed in its construction in order to facilitate emptying, cleaning, and replacement. The bulbs containing the water were a pair of 2-litre aspirator bottles, and a large filter flask served as a trap between the second bulb and the vacuum pump.

In order to achieve complete extraction of the dust particles the bubble stream was made as fine as possible by leading the air from the first bulb through the pores of a Gooch crucible fitted into the neck of the second bulb. The coarser particles, such as whole cotton hairs, were all removed by the water in the first bulb whilst any of the smaller particles which succeeded in passing this were dispersed in the fine bubble stream entering the second bulb and retained there.

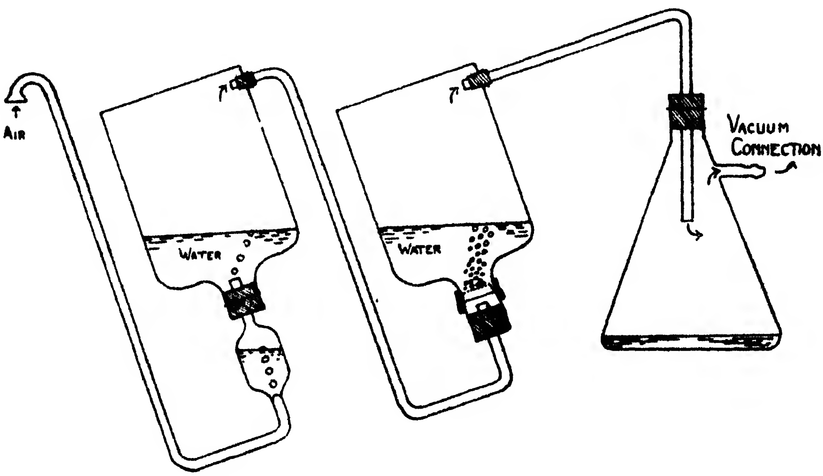


FIG. 4

After an experiment the apparatus was emptied and the water with the dust in suspension gently boiled. One per cent. of formalin was then added to prevent fermentation taking place before the analysis could be started. The dust was recovered from the water on a tared filter paper and dried to constant weight at 110° C. The portion of the dust readily soluble in water was of minor importance for the purposes of this investigation, and on this account the filtrate was neglected.

When dried, the dust was reduced to ash and again weighed to determine the amount of inorganic material. To fix the silica it was twice taken to dryness on the steam bath with concentrated hydrochloric acid, then moistened with this acid and diluted with nearly boiling water. After filtration the dry filter paper was ignited and the amount of silica determined. The filtrate, which contained chiefly iron salts, was discarded.

Ten samples, collected and analysed in this matter, gave figures which showed that about 90 per cent. of the dust* was composed of organic matter, that is, cotton hair fragments, seed coat particles, and fungus spores. The actual values obtained varied only from 86 per cent. to 92 per cent. The inorganic portion varied from 8 per cent. to 14 per cent.—average 10 per cent.—and approximately 60 per cent. of this was silica. Iron compounds formed the chief portion of the remainder.

Middleton[1] (p. 443) states that the mineral matter varies within very wide limits. This is true of the actual quantity present but the proportion to organic matter is approximately the same in all samples.

The character of the dust does not seem to vary greatly with the kind of cotton or mixing but the quantity of particles and the proportion of different kinds of particles vary widely. For example, the number of black mildew spores of *Aspergillus niger* was much greater in the sample of Egyptian Uppers (Plate II, 5) than in the sample of Texas (Plate II, 6).

In addition, there is a remarkable similarity in kind between the dust from the card room air, that inside the chain of flats, the air in the vicinity of the cylinder or doffer during stripping, or 3 in. from the flat stripping brush during the cleaning of this. Only when cleaning out the undercasings was there a difference and this difference was chiefly one of size.

SUMMARY

1. An investigation is described of the dust produced during carding in 17 card rooms covering as wide a range of practical conditions as possible.

2. It is shown that the dust consists mainly of very minute, almost invisible particles, and in addition a few large particles, chiefly fragments of fibre, which although so obvious to the eye may be numerically unimportant.

3. The sampling of the air by Owen's jet extraction apparatus, the computation of the minute particles, and the expression of the results are described.

4. As much as one per cent. of the dust might consist of fungus spores, especially those of the mildew organisms belonging to the *Aspergillus niger* group.

REFERENCES

[1] Middleton, E. L. "Dust in Cotton Card Rooms" *Journal of Industrial Hygiene*, 1926, viii, 436.

[2] Owens, J. S. "Fourth Annl. Rept. Adv Comm. on Atmos. Pollution." See also *Analyst*, 1926, **51**, 2–18.

[3] Owens, J. S. *Proc. Royal Soc*, 1922, A**101**, 18–37. See also *Analyst*, 1926, **41**, 2–18.

Shirley Institute
Didsbury

29th October 1930

* At a later date, when opening machinery was used that incorporated the "Shirley" high-speed dust cage (E.P. 317,952) and special laboratory apparatus was employed to separate the very finest particles of dust, it was found that the very fine dust removed from cotton by this cage contained a large proportion of mineral matter (up to 80%) and a very small amount of nitrogenous matter.

THE
Journal of the Textile Institute

VOL. XXI—1930

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